高等院校精品规划教材

ENGLISH FOR GEOLOGICAL AND GEOTECHNICAL ENGINEERING

地质与岩土工程专业英语

李华晔 刘汉东
王四巍 于怀昌 编著

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内 容 提 要

本书以培养学生英语专业文献阅读和翻译能力为主要目标，内容包括岩石学、构造地质学、地形地貌学、地震学、地下水动力学、工程地质学、岩体力学、土力学、地基与基础工程、水利工程、喷锚支护与盾构施工等方面的基础知识。全书由20个单元组成，每个单元均有译文。书后附有科技文章翻译和写作指南及生词表。

本书可作为地质工程、岩土工程、水利工程、土木工程等专业的本科生和研究生的教材或课外阅读材料，也可供从事相关专业的工程技术人员、管理人员和教师参考。

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前 言

自 1987 年，笔者在华北水利水电学院为水文地质与工程地质专业讲专业英语至今已 20 多年，先后编写了两次内部教材供学生使用。从 2000 年以来一些教师建议由笔者牵头编写一本适合地质与岩土工程的专业英语教材，于是笔者按照教育部颁发的《大学英语教学大纲》英语教学 4 年不间断的精神，根据教育部学科和专业调整目录开始进行材料收集和编写工作，经两年半的时间，编著了《地质与岩土工程专业英语》一书。

本书涉及的内容包括岩石学、构造地质学、地形地貌学、地震学、地下水动力学、工程地质学、岩体力学、土力学、地基与基础工程、水利工程、喷锚支护与盾构施工等方面的基础知识，旨在为两个专业学生阅读英文文献打下专业词汇和理解原文的基础。为了提高学生的专业知识和英语写作水平，编写了科技文章翻译和写作指南及生词表供读者查阅。

全书共分 20 个单元，每个单元分为两部分——课文和阅读材料，均给出了参考译文和词汇表。20 个单元课堂教学全部讲授一般需 40 ~ 50 学时，如学时不够，可根据专业性质有针对性地讲解一些相关的内容。本书语言规范、内容广泛、针对性强，有利于自学。

参加本书编著的有华北水利水电学院李华晔、刘汉东、王四巍和于怀昌。

全书由李华晔教授统稿并对原文、译文进行了多次校对，但由于编者水平有限，错误和不足之处在所难免，恳请广大读者批评指正。

编著者

2007 年 12 月

目　录

Unit 1

Text

Igneous Rock

1 What is Magma

Magma is molten rock that flows within the earth. It may be completely liquid or, more commonly, a fluid mixture of liquid, solid crystals, and dissolved gases. When magma reaches the Earth's surface, we call it lava, or molten rock that flows above ground.

Magma forms when underground temperatures become high enough to break the bonds in some minerals, causing the minerals to melt. The rock then changes from a crystalline solid to a fluid mix containing freely moving ions and atoms as well as some still-solid crystalline fragments. Different minerals melt out of the rock at different temperatures as the heat gradually increases, with the minerals having the highest melting points remaining the longest as still-solid fragments in the magma. At the same time, the composition of the magma changes as each newly molten mineral enters and enriches it.

When heat dissipates from magma, its bonds no longer break and new bonds start to form. Firstly, some of the free atoms and ions in the liquid bond to form tiny crystals. Additional ions and atoms bond at prescribed sites in the crystal structures. The crystals grow until they touch the edges of adjacent crystals. As cooling progresses, different minerals crystallize from the magma, again changing the magma's composition. If cooling continues long enough, the entire body of magma will become solidified as igneous rock.

2 Classification of Igneous Rocks

Igneous rocks are classified based on their two most obvious properties: their texture, which is determined by the size and shape of their mineral crystals and the manner in which these grew together during cooling, and their composition, which is determined by the minerals that they contain.

3 Igneous Textures

A rock's texture refers to the appearance of its surface—specifically the size, shape, and arrangement of the rock's mineral components. The most important factor controlling these features in igneous rocks is the rate at which a magma or lava cools. When a magma's minerals crystallize slowly underground over thousands of years, crystals have ample time to grow large

enough to be seen clearly with the unaided eye. The resulting texture is called phaneritic rocks (Fig. 1.1). Slow cooling occurs when magmas enter, or intrude, preexisting solid rocks; thus rocks with phaneritic textures are known as intrusive rocks. They are also called plutonic rocks.

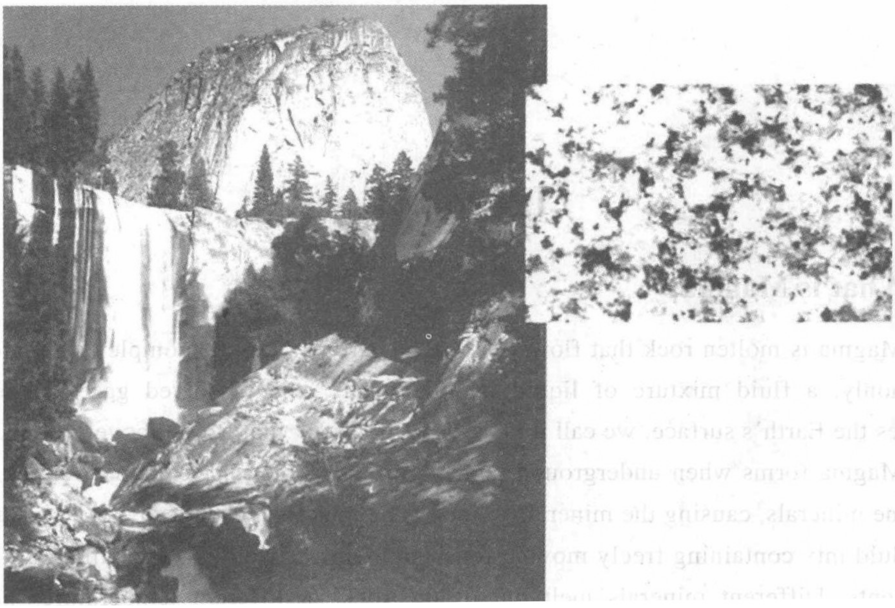


Figure 1.1 Phaneritic rocks
Rocks that solidify slowly underground, as did this granite in Yosemite National Park, California have phaneritic (coarse-grained) textures

Some igneous rocks develop at relatively low temperatures from ion-rich magmas containing a high proportion of water. Under these conditions, ions move quite readily to bond with growing crystals, enabling the crystals to become unusually large (sometimes several meters long). Rocks with such exceptionally large crystals are called pegmatites (Fig. 1.2). In western Maine, near the towns of Bethel and Rumford, some pegmatitic rocks contain 5-meter long crystals of the mineral beryl.

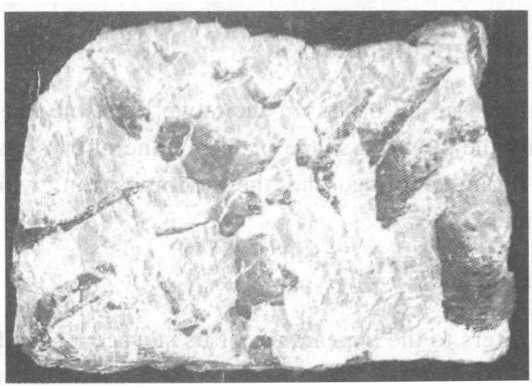


Figure 1.2 Pegmatites
Extremely coarse-grained pegmatites, such as the one shown here, form from ion-rich magmas having a high water content

Some igneous rocks solidify from lava so quickly that their crystals have little time to grow. These aphanitic rocks have crystals so small that they can barely be seen with the naked eye (Fig. 1.3). Rocks with aphanitic textures are called extrusive rocks, because they form from lava that has flowed out, or been extruded, onto the Earth's surface. They are also known as volcanic rocks, because lava is a product of volcanoes.

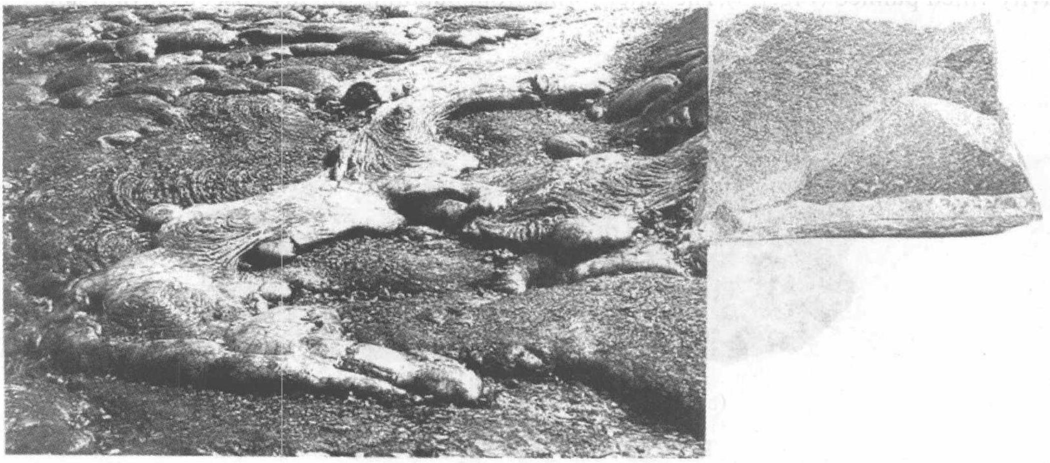


Figure 1.3 Volcanic rocks
Volcanic rocks, such as this basalt, typically have aphanitic (very small-grained) textures, because they solidify rapidly above ground

In some igneous rocks, large, often perfect, crystals are surrounded by regions with much smaller or even invisible grains (Fig.1.4). These porphyritic textures are believed to form as a result of slow cooling followed abruptly by rapid cooling. First, gradual underground cooling produces large crystals that grow slowly within magma. Next, the mixture of remaining liquid magma and the early-formed crystals is forced close to the surface or actually escapes into the air. There the liquid cools rapidly to produce the body of smaller grains that envelops the larger crystals.

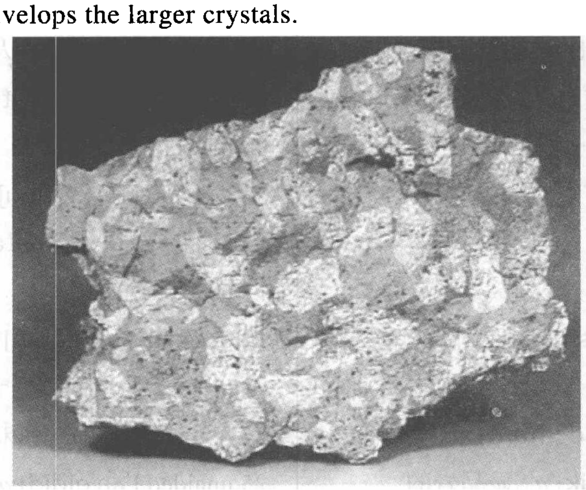
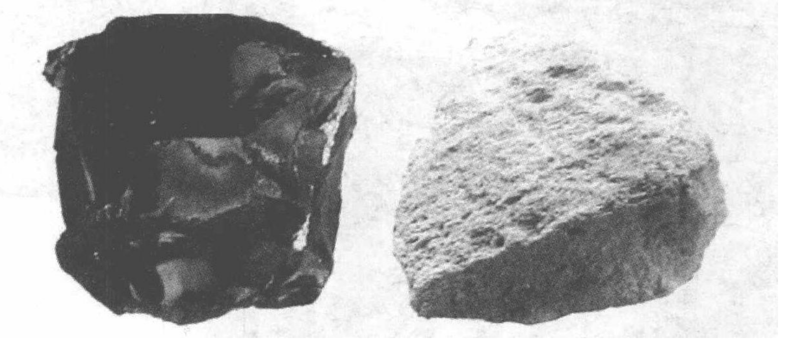


Figure 1.4 Porphyritic rocks
Some rocks have a porphyritic texture, marked by large crystals surrounded by an aphanitic matrix

When lava from a volcano erupts into the air or flows into a body of water, much of it cools so quickly that its ions don't have time to become organized into any crystals. The texture of the resulting rock is described as glassy. Two common types of volcanic glass exist, both produced by instantaneous cooling of lava: dark-colored obsidian and light-colored, cavity-filled pumice (Fig.1.5).The latter forms from bubbling, highly gaseous lava foam.



(a) (b)

Figure 1.5 Glassy volcanic rocks

Obsidian (a) and pumice (b) contain no crystals because they solidify instantaneously. Pumice, which forms from lava foam, commonly has so many tiny air-filled cavities that it can float in water

New Words and Expressions

1.magma ['mægmə] *n.* 岩浆

2.lava ['lɑːvə] *n.* 熔岩，火山岩

3.crystalline ['kristəlain] *a.* 晶质的

4.crystalline solid 结晶固体

5.fragment ['frægmənt] *n.* 碎屑，碎片

6.enrich [in'ritʃ] *vt.* 使富足，使肥沃

7.dissipate ['disipeit] *v.* 驱散，(使)(云、雾、疑虑等)消散

8.solidify [sə'lidifai] *n.* 凝固，结晶

9.igneous ['igniəs] *a.* 火成的

10.classification [ˌklæsifi'keiʃən] *n.* 分类，分级

11.arrangement [ə'reindʒmənt] *n.* 排列

12.phaneritic [fænə'ritik] *a.* 显晶岩的

13.plutonic [pluː'tɔnik] *a.* 深成的，火成的(岩石)

14.pegmatite ['pegmətait] *n.* 结晶花岗岩

15.beryl ['beril] *n.* 绿玉，绿柱石

16.aphanitic [ˌæfə'nitik] *a.* 非显晶(质)的，隐晶(质)的

17.name for 与(另一人)同名

18.porphyritic [ˌpɔːfi'ritik] *a.* 斑状的

19.matrix ['meitriks] *n.* 基质

20.volcano [vɔl'keinəu] *n.* 火山

21.instantaneous [ˌinstən'teinjəs] *a.* 瞬间的，即刻的

22.obsidian [ɔb'sidiən] *n.* 黑曜岩

23.pumice ['pʌmis] *n.* 浮岩

24.foam [fəum] *n.* 泡沫，水沫

25.unaided ['ʌn'eidid] *a.* 无助的，独立的

26.unaided eye 肉眼

火成岩

一、什么是岩浆

岩浆是在地球内部流动熔化的岩石。岩浆可以是完全液态的，或者是更常见的液体、固态晶体和溶解气体组成的流动混合物。当岩浆到达地表，我们称之为熔岩，或者叫在地表流动的熔岩。

当地下温度增高到足以破坏某些矿物连接时，导致矿物熔化就形成了岩浆。然后岩石从结晶固体变为液态混合物，但它包含自由运动的离子和原子以及一些仍然保持固态的晶质碎屑。当热量逐渐增加时，不同的矿物在不同温度下会从岩石中熔化分离，熔点最高的矿物在岩浆中以固态碎屑形式保持时间最长。同时，当有新熔化的矿物混入和富集时，岩浆的成分发生改变。

当热量从岩浆中消散后，矿物的胶结不再受到破坏，重新胶结开始形成。首先，液体中的一些自由原子和离子结合形成微小晶体。增加的离子和原子会在晶体结构特定位置处胶结。晶体生长直到触及相邻晶体边缘才停止。当冷凝发生时，不同的矿物从岩浆中结晶，再次改变了岩浆成分。如果冷凝时间足够长，整个岩浆体将变成固体即火成岩。

二、火成岩的分类

火成岩是根据其两个非常明显的特征分类：火成岩的结构与成分。火成岩的结构由其矿物晶体的大小、形状以及这些矿物晶体在冷凝过程中的生长方式来确定；火成岩的成分由岩石所含有的矿物来确定。

三、火成岩结构

岩石的结构指岩石表面的特性，尤其矿物大小、形状和排列方式。在火成岩中控制这些特征的最重要因素是岩浆或熔岩的冷却速率。当岩浆中的矿物在地下缓慢结晶上千万年，晶体就有充足时间生长变大，用肉眼可以看得很清楚。产生的结构被称为显晶质(见图 1.1)。当岩浆进入或侵入已存在的岩石中，缓慢冷却，岩石具有显晶质结构叫侵入岩。侵入岩也被称为深成岩。

一些火成岩在相对较低温度下从富含离子的岩浆中形成，这种岩浆含有高比例的水分。在此条件下，离子移动，非常容易与正在生长的晶体结合，使晶体变得异乎寻常的大(有时几米长)。含有这样异常巨大晶体的岩石被称为伟晶岩(见图 1.2)。在西缅因州，靠近 Bethel 和 Rumford 城，一些伟晶岩含有 5 m 长的矿物绿柱石晶体。

一些火成岩从熔岩中固结速度非常快，以至于矿物晶体生长时间很短。这些隐晶质岩石中的晶体非常小，以至于用肉眼几乎看不到晶体(见图 1.3)。具有隐晶质结构的岩石被称为喷出岩，它们是由流出或喷出地表的熔岩形成。熔岩是火山的产物，所以喷出岩也被认为是火山岩。

在一些火成岩中，较大的、通常完好的晶体被许多细小的、甚至看不见的颗粒在边界包围着(见图 1.4)。这些斑状结构被认为是开始缓慢冷却其后突然快速冷却的结果。首

先，在地下逐渐冷却产生大的晶体，但它在岩浆中生长很慢。然后，剩余的液态岩浆和早期形成的晶体组成的混合物受到约束接近地表甚至冲入大气。液体在这里快速冷却，产生包裹较大晶体的小颗粒体。

当火山中的熔岩喷到大气中或流入水体，熔岩的大部分快速冷凝，熔岩中的离子来不及改变原结构而形成晶体。产生的岩石结构叫做玻璃质。火山玻璃质两种常见类型都是由熔岩瞬间冷凝形成的：暗色的黑曜岩和浅色的、充满孔洞的浮岩(见图 1.5)。后者是由带泡的、高度气态化的熔岩泡沫形成。

Reading Material

Igneous Rock

4 Igneous Compositions

The Earth's magmas consist largely of the most common elements: oxygen, silicon, aluminum, iron, calcium, magnesium, sodium, potassium, and sulfur. The relative proportions of these components found at any given time within a body of magma give the magma its distinctive characteristics and ultimately determine the mineral content of the rocks it will form. Igneous rocks and magmas are classified into four main compositional groups—ultramafic, mafic, intermediate, and felsic—based on the proportion of silica (oxygen and silicon) they contain (Table 1.1). Figure 1.6 shows how the mineral content of igneous rocks varies in these categories.

Table 1.1 Common Igneous Compositions

Composition Type	Percentage of Silica	Other Major Elements	Relative Viscosity of Magma	Temperature at Which First Crystals Solidify	Igneous Rocks Produced
Felsic	>65%	Al, K, Na	High	600~800 °C (1 112~1472°F)	Granite (plutonic) Rhyolite (volcanic)
Intermediate	55%~65%	Al, Ca, Na, Fe, Mg	Medium	800~1 000 °C (1 472~1 832 °F)	Diorite (plutonic) Andesite (volcanic)
Mafic	40%~55%	Al, Ca, Fe, Mg	Low	1 000~1 200 °C (1 832~2 192 °F)	Gabbro (plutonic) Basalt (volcanic)
Ultramafic	<40%	Mg, Fe, Al, Ca	Very low	>1 200 °C (2 192 °F)	Peridotite(plutonic) Komatiite(volcanic)

Ultramafic Igneous Rocks The term "mafic" is derived from magnesium and ferrum.

Ultramafic igneous rocks are dark in color and very dense, because they are dominated by the iron-and magnesium-containing silicate minerals (called ferromagnesian minerals) olivine and pyroxene and contain relatively little silica (less than 40%).The most common ultramafic rock, peridotite, contains 40% to 100% olivine. Ultramafic rocks generally crystallize slowly deep within the Earth's interior and appear at the Earth's surface only where extensive erosion has removed overlying crustal rocks. They are most likely to be found near continental collision plate boundaries, where deep rocks have been uplifted.

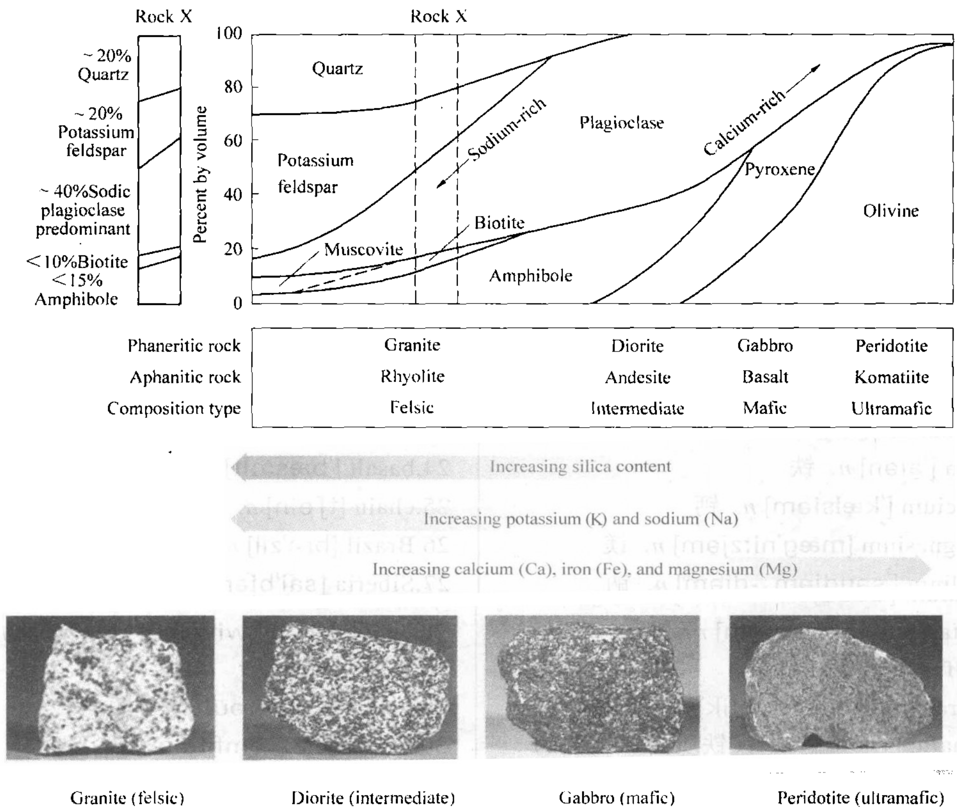


Figure 1.6 An igneous rock classification chart

Compositional types among the igneous rocks range from felsic to ultramafic. The mineral components of the rocks are indicated by colored areas in the body of the chart (The sample segment shows how to interpret the chart, using as an example a rock falling between granite and diorite in composition)

Mafic Igneous Rocks Mafic igneous rocks have a silica content ranging between 40% and 55%, with the principal minerals being pyroxene, calcium feldspar, and a minor amount of olivine. They are the most abundant rocks of the Earth's crust; the aphanitic volcanic rock basalt is the single most abundant of them. Most of the ocean floor and many islands, such as the Hawaiian chain, are composed of basalt. Basalt also constitutes vast areas of our continents and is found in Brazil, India, South Africa, Siberia, and the Pacific Northwest of North America, the plutonic equivalent of basalt is gabbro; it has the same composition as basalt but, because it cools more slowly deep within the Earth, is coarse-grained.

Intermediate Igneous Rocks Intermediate igneous rocks contain more silica than mafic rocks, including between 55% and 65% silica, and are generally lighter in color. They typically consist of some ferromagnesians, such as pyroxene and amphibole, along with sodium-and aluminum-rich minerals such as sodium feldspar and mica, and a small amount of quartz. Examples of intermediate igneous rocks include the aphanitic volcanic rock andesite (named for the Andes Mountains of South America, where this type of igneous rock dominates the local geology) and its phaneritic plutonic equivalent diorite.

Felsic Igneous Rocks The term "felsic" is derived from feldspar and silica. Felsic igneous rocks contain more silica—65% or more —than either mafic or intermediate igneous rocks. They are generally lighter in color because they are poor in iron, magnesium, and calcium silicates, but rich in potassium feldspar, aluminum-rich (muscovite) mica, and quartz. Examples of felsic igneous rocks include the common plutonic phaneritic rock granite and its volcanic aphanitic equivalent, rhyolite. Rocks of felsic composition have a greater variety of textures than any other igneous rock and include several glassy rocks and ultra-coarse pegmatites.

New Words and Expressions

1.silicon ['silikən] *n.* 硅，硅元素
2.aluminum [ə'lju:minəm] *n.* 铝
3.iron ['aiən] *n.* 铁
4.calcium ['kælsiəm] *n.* 钙
5.magnesium [mæg'ni:zjəm] *n.* 镁
6.sodium ['səudjəm, -diəm] *n.* 钠
7.potassium [pə'tæsjəm] *n.* 钾
8.sulfur ['sʌlfə] *n.* 硫
9.ultramafic [ˌʌltrə'mæfik] *a.* 超基性的
10.mafic ['mæfik] *a.* 镁铁质的，镁铁的
11.intermediate [ˌintə'mi:djət] *a.* 中间的
12.felsic ['felsik] *n.* 长英质的(矿物)
13.silica ['silikə] *n.* 二氧化硅
14.ferrum ['ferəm] <拉> *n.* 铁
15.silicate ['silikit] *n.* 硅酸盐
16.ferromagnesian [ˌferəumæg'ni:ʃən] *a.* 含有铁镁的
17.olivine [ˌɔli'vi:n] *n.* 橄榄石
18.pyroxene [pai'rɔksi:n] *n.* 辉石
19.peridotite [ˌperi'dəutait] *n.* 橄榄岩
20.crystallize ['kristəlaiz] *vi.* 结晶
21.uplift [ʌp'lift] *v.* 举起，升起，隆起
22.principal mineral 主要矿物
23.feldspar ['feldspɑ:] *n.* 长石
24.basalt ['bæsɔ:lt] *n.* 玄武岩
25.chain [tʃein] *n.* 链，山脉
26.Brazil [brə'zil] *n.* 巴西
27.Siberia [sai'biəriə] *n.* 西伯利亚
28.equivalent [i'kwivələnt] *n.* 等价物，同期地层
29.gabbro ['gæbrəu] *n.* 辉长岩
30.amphibole ['æmfibəul] *n.* 闪石
31.mica ['maikə] *n.* 云母
32.quartz [kwɔ:ts] *n.* 石英
33.andesite ['ændizait] *n.* 安山岩
34.diorite ['daiərait] *n.* 闪长岩
35.calcium silicate 硅酸钙
36.muscovite [ˌmʌskə'vait] *n.* 白云母
37.granite ['grænit] *n.* 花岗岩
38.rhyolite ['raiəˌlait] *n.* 流纹岩
39.pegmatite ['pegmətait] *n.* 伟晶岩
40.terrestrial [ti'restriəl] *a.* 地球的，大地的
41.as well as 既……又

阅读材料

火 成 岩

四、火成岩的成分

地球的岩浆通常主要由以下元素组成：氧、硅、铝、铁、钙、镁、钠、钾和硫。某一时间在岩浆中所发现的相关成分相对比例会使岩浆具有自身与众不同的特性，并最终决定了所形成岩石中矿物的含量。根据二氧化硅(氧和硅)的比例，火成岩与岩浆被分为四种主要成分组：超基性、铁镁质、中性和长英质(见表 1.1)。图 1.6 显示了在这些分类中火成岩的矿物成分是如何变化的。

超基性火成岩　术语“铁镁质的”来自镁和铁。超基性火成岩颜色深，非常致密，这是由于岩石主要由铁镁的硅酸盐矿物(称为铁镁矿物)橄榄石和辉石组成，含相对少量的二氧化硅(小于 40%)。最常见的超基性岩——橄榄岩含 40%～100%的橄榄石。超基性岩通常在地球深部缓慢结晶，当覆于其上的岩石受到剥蚀才会在地表出露。在大陆板块碰撞边界附近会发现这类岩石，因为在这里它们受到抬升。

铁镁质火成岩　铁镁质火成岩中二氧化硅含量为 40%～55%，主要矿物为辉石、钙长石和少量橄榄石。铁镁质火成岩是地壳中含量最丰富的岩石；隐晶质火山玄武岩是铁镁质火成岩中含量最多的一种。洋底的大部分和许多岛屿，如夏威夷山脉，都是由玄武岩组成的。玄武岩也形成了我们大陆的广阔区域，在巴西、印度、南非、西伯利亚和北美洲的太平洋西北地区都发现了玄武岩，玄武岩的深成同类岩石是辉长岩；辉长岩与玄武岩成分相同，但因为辉长岩在地球深部冷却更缓慢，所以颗粒粗大。

中性火成岩　中性火成岩比铁镁质岩石二氧化硅含量更多，含量为 55%～65%，通常颜色更浅。中性火成岩典型成分是铁镁矿物，如辉石和闪石，以及富含钠和铝的矿物如钠长石和云母，和少量的石英组成。中性火成岩的实例有隐晶质火山安山岩(以南美洲安第斯山命名，在那里这种类型火成岩控制了区域地质)，它的显晶深成岩为闪长岩。

长英质火成岩　术语“长英质的”来源于长石和二氧化硅。长英质火成岩比铁镁质或中性火成岩的二氧化硅含量更高，含量在 65%或更多。因为长英质火成岩中含铁、镁、钙硅酸盐少，但富含钾长石、富铝(白云母)云母和石英，所以通常颜色更浅。长英质火成岩的实例包括常见的深成显晶质花岗岩和其火山隐晶质同类流纹岩。长英质火成岩结构比其他火成岩的结构种类更多，包括一些玻璃质岩石和超大颗粒的伟晶岩。

Unit 2

Text

Sedimentary Rocks

1 The Origins of Sedimentary Rocks

Sediments are classified according to the source of their constituent materials as either detrital or chemical (Fig.2.1). Detrital sediment is composed of solid fragments, or detritus, of

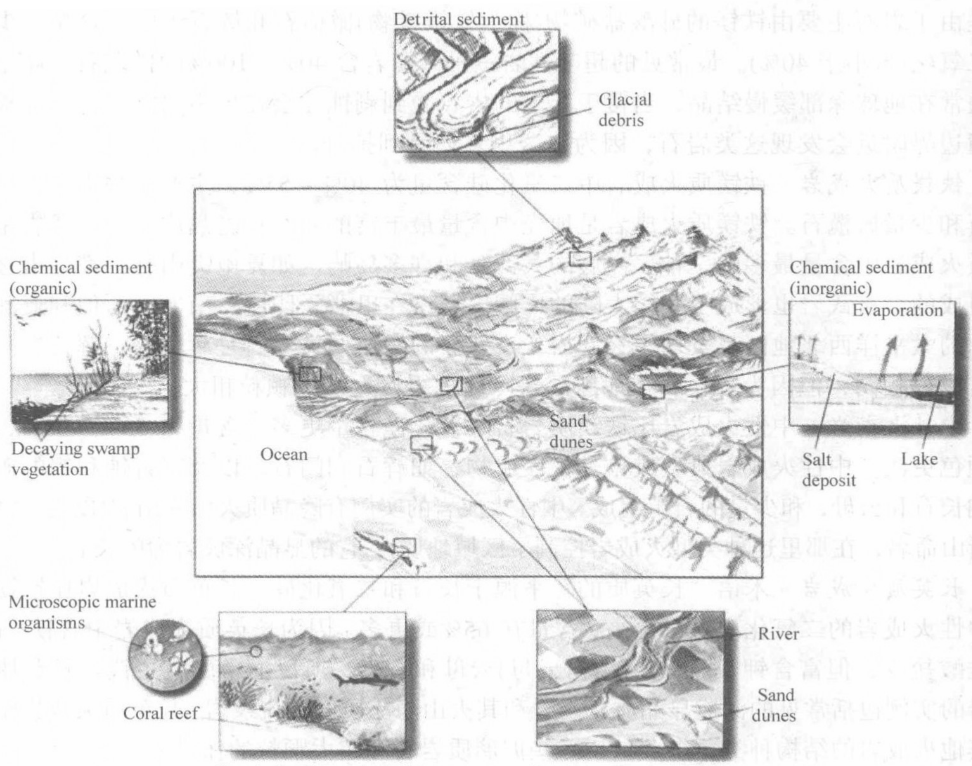


Figure 2.1 Various types of sediments and their origins

Detrital sediments, such as glacial debris or river-channel sand, consist of preexisting rock fragments. Chemical sediments often consist of minerals precipitated directly from water, such as salt deposits produced by evaporation of small temporary lakes; they may also be composed of organic debris, such as partially decayed swamp vegetation or the shells of small marine organisms

preexisting igneous, sedimentary, or metamorphic rocks. Chemical sediment forms from previously dissolved minerals that have either precipitated from solution in water or been extracted from water by living organisms and converted to shells, skeletons, or other organic substances (which are deposited as sediment when the organisms die or discard their shells). Through various processes, each type of sediment may be transformed into sedimentary rock.

2 Sediment Transport and Texture

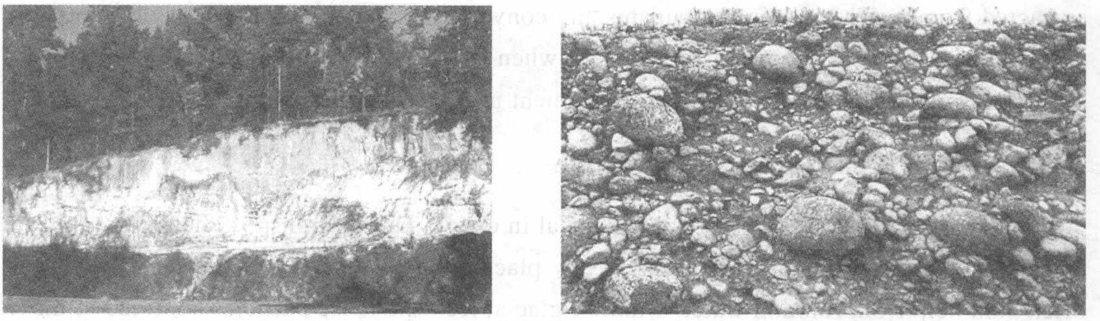
The vast majority of sediments are detrital in origin. During transport, detrital sediments are generally carried from high places to low places; they are moved largely by gravity but often gain help from running water, wind, or glacial ice. The loose particles continue to move until the transporting medium loses its capacity to carry them, such as when a river ceases to flow upon entering relatively still marine water at a coast. At this point, the particles drop to the bottom and are deposited. Each year, an estimated 10 billion tons of detrital sediment, most of it carried by rivers, is delivered to the world's oceans.

If you've ever held a handful of beach sand or lake-bottom mud, you can appreciate the variety of textures that characterize detrital sediments. Detrital sediment texture—the size, shape, and arrangement of the sediment particles—depends on the source of the particles and the medium that transported them. (Chemical sediments, which we discuss later, are distinguished by their composition more than by their texture)

Grain Size Because rock fragments continue to be weathered during transport, they are generally reduced in size when they are finally deposited as sediment. The extent to which they become worn down depends partly on their constituent minerals' resistance to weathering and partly on the nature of their parent rocks. Coarse-grained granite, for example, generally weathers to produce grains larger than those created by the weathering of fine volcanic ash. The nature and energy level of the transport medium also influence sediment grain size. For example, a pebble that would be pulverized by a creeping glacier might remain unchanged by an oozing mudflow; it might be worn down by a white-water river but be unaffected by a trickling stream.

Geologists can often determine the medium that transported a sediment by making a quick visual estimate of its sorting. Sorting is the process by which a transport medium separates or "selects" particles of different sizes, shapes, or densities. Wind, which generally carries rely relatively small particles, is the most selective of the transport media; a deposit of windblown silt, which comprises particles mostly within a narrow size range, is considered well sorted (Fig.2.2(a)). At the other extreme, glacial ice is unselective, transporting particles with a wide range of sizes. Glacial deposits, which may contain extremely fine particles as well as boulders the size of small office buildings, are said to be poorly sorted (Fig.2.2(b)). Sorting of sediment can also reflect changing energy levels in the transport medium. When a moving current (wind or water) loses energy, its capacity to carry sediments is diminished.

Because it takes more energy to carry them, the larger, heavier particles are deposited first. As energy diminishes further, the finer particles settle out.



(a) (b)

Figure 2.2 Differential sediment sorting by transport media

(a)Because wind is highly selective regarding the particles it transports, this well-sorted windblown silt near Vicksburg, Mississippi, is limited to very fine sediment particles. (b) Glaciers are capable of transporting sediment of all sizes. Their deposits, such as this one in Rocky Mountain National Park, Colorado, are typically very poorly sorted

Grain Shape Sediment particles may be either angular or rounded depending on the transport medium, the distance the particles are carried, and the hardness of the particle minerals. Some transport media are particularly efficient in rounding particles. Swiftly flowing rivers, for instance, bounce pebbles and sand grains around vigorously, so that they collide with other particles and with the river bottom; as a result, the sediment becomes ever smoother and smaller. A stream that carries particles for long distances will round the grains much more than a stream of comparable energy that carries them for only a short distance. Glaciers, on the other hand, embed some of their sediment particles in hundreds of meters of ice, so that, regardless of the distance they are carried, they remain angular when the glacier finally deposits them.

Grains of softer minerals, such as gypsum and calcite, become rounded more readily than grains of harder ones, such as quartz. In a recent field study, fragments of soft sedimentary rock became well rounded after only 11 km of stream transport. More durable fragments of granite, is transported in the same stream, required 85 to 335 km of transport to achieve comparable roundness.

New Words and Expressions

1.sedimentary [sedi'mentəri] *a.* 沉积的，沉淀性的

2.detrital [di'traitəl] *a.* 碎屑的，由岩屑形成的

3.fragment ['frægmənt] *n.* 碎片，断片

4.detritus [di'traitəs] *n.* 岩屑，碎石，砂砾

5.preexist [ˌpriːig'zist] *v.* 先前存在

6.igneous ['igniəs] *a.* 火成的

7.metamorphic [ˌmetə'mɔːfik] *a.* 变成的，变质的

8.precipitate [pri'sipiteit] *vt.* 使沉淀(出)，析出
9.extract [iks'trækt] *vt.* 提炼出，分离出
10.skeleton ['skelitən] *n.* 骨架，框架
11.organic [ɔ:'gænik] *a.* 有机的
12.texture ['tekstʃə] *n.* 结构
13.glacial ['gleisjəl, 'glæs-] *a.* 冰的，冰河的
14.handful ['hændful] *n.* 一把，一撮
15.grain size 粒度，颗粒尺寸
16.weather ['weðə] *vt.* 侵蚀 *vi.* 风化
17.resistance [ri'zistəns] *n.* 抗蚀性
18.coarse-grained ['kɔ:s'greind,'kours-] *a.* 粗粒的
19.granite ['grænit] *n.* 花岗岩
20.pebble ['pebl] *n.* 砾石，小砾
21.pulverize ['pʌlvəraiz] *v.* 研磨成粉
22.glacier ['glæsjə, 'gleiʃə] *n.* 冰河，冰川
23.ooze [u:z] *v.* 渗出，慢慢流出
24.mudflow ['mʌdfləu] *n.* 泥流
25.white-water ['hwait,wɔ:tə, -,wɔtə,'wait-] *a.* 白浪的
26.trickle ['trikl] *vi.* 淌，细流
27.visual estimation 目测，目视估测
28.sorting ['sɔ:tiŋ] *n.* 分选
29.selective [si'lektiv] *a.* 选择的，选择性的
30.windblown ['wind,bləun] *n.* 风蚀的，风积的
31.silt [silt] *n.* 粉砂
32.well sorted 分选良好的
33.boulder ['bəuldə] *n.* 漂砾，巨砾
34.current ['kʌrənt] *n.* 流
35.grain shape 晶粒形状
36.angular ['æŋgjulə] *a.* 棱角状的
37.swiftly [swiftli] *adv.* 很快地，即刻
38.bounce [bauns] *v.* (使)反跳，弹起
39.embed [im'bed] *vt.* 使插入，使嵌入
40.gypsum ['dʒipsəm] *n.* 石膏
41.calcite ['kælsait] *n.* 方解石
42.roundness ['raundnis] *n.* 圆度

沉 积 岩

一、沉积岩的起源

沉积物根据其组成物的来源可分为碎屑型或化学型(见图 2.1)。碎屑沉积物由固体碎片或先前存在的火成岩、沉积岩或变质岩的岩屑组成。化学沉积物由先前溶解的矿物形成，这些矿物或者从水溶液中沉淀出来，或者被活体生物从水中分离并转化成贝壳、骨架或其他有机物质(当有机物死亡或丢弃它们的壳体时，这些有机物质形成沉积物)。通过不同的过程，各种类型的沉积物都可以被转化为沉积岩。

二、沉积物的搬运和结构

绝大多数沉积物来源于碎屑。在搬运过程中，碎屑沉积物一般被从高处搬运到低处；它们主要在重力作用下被搬运，但流水、风或冰川也经常起作用。直到搬运介质失去它的搬运能力时，松散的颗粒才停止移动，如河流在海滨处流入相对静止的海水中时便停止流动。在这里，颗粒下沉到水底并沉积起来。每年大约 100 亿吨的碎屑沉积物被运到世界各大洋，其中绝大部分碎屑物是由河流搬运的。

如果你曾经抓过一把海滩砂或湖底淤泥，你就能辨别代表碎屑沉积物特点的各种结构。碎屑物的结构——沉积物颗粒的大小、形状和排列依赖于颗粒来源和搬运介质。(后

面我们要讨论的化学沉积物，主要通过沉积物的成分而不是结构进行辨别)

颗粒大小　由于岩石碎屑在搬运过程中继续被风化，所以当最终形成沉积物时，一般碎屑尺寸会减小。碎屑被磨损的程度部分依赖于构成矿物的抗风化能力，部分依赖于母岩的性质。例如，粗粒花岗岩风化产生的颗粒一般要比细粒火山灰风化产生的颗粒大。搬运介质的性质和能量也影响沉积物的颗粒大小。例如，可以被蠕动冰川磨成粉末的卵石，在缓慢流动的泥流中却能保持不变；卵石可以被奔腾的河流磨损，却不受涓涓细流的影响。

地质学家经常通过快速目测沉积物的分选来确定搬运沉积物的介质。分选是搬运介质分离或挑选的过程，即它们的大小、形状或颗粒密度受到筛分。风，通常仅搬运相对较小的颗粒，是最具选择性的搬运介质；主要由大小相近颗粒组成的风积粉沙沉积物，被认为分选性好(见图 2.2(a))。另一方面，冰川不具选择性，搬运的颗粒尺寸变化大。冰川沉积物可能既包含非常细小的颗粒又包含小型办公楼大小的巨砾，因此分选性差(见图 2.2(b))。沉积物的分选也能反映搬运介质能量的变化。当运动流体(风或水)失去能量，其搬运沉积物的能力减小。因为要耗费更多能量搬运，较大较重的颗粒首先沉积。当能量进一步减小时，细小的颗粒也会被沉积。

颗粒形状　沉积物颗粒可以是棱角状的或磨圆状的，这取决于搬运介质、颗粒被搬运距离和矿物颗粒硬度。一些搬运介质可以非常有效地磨圆颗粒。例如，快速流动的河水使卵石和砂粒剧烈地弹起，因而卵石和砂粒与其他颗粒或河床碰撞；结果沉积物变得更加光滑细小。长距离搬运颗粒的溪流和相类似能量短距离搬运颗粒的溪流相比会更强烈地磨圆颗粒。另一方面，冰川将一些沉积物颗粒嵌入到冰内几百米深处，因此不管这些沉积物被搬运距离的远近，最后被沉积下来时它们仍保持棱角状。

硬度低的矿物颗粒如石膏和方解石，比硬度高的矿物颗粒如石英更容易被磨圆。在一次近期的现场研究中，软沉积岩碎片仅经过 11 千米的溪流搬运就被磨圆。更坚硬的花岗岩碎片，在同一溪流中被搬运，则要经过 85~335 千米搬运才能达到较好的磨圆度。

Reading Material

Sedimentary Rocks

3 Sedimentary Structures

Sediments often contain sedimentary structures, physical features that develop during or soon after deposition and reflect the conditions under which the sediments settled. These structural clues, along with any fossils present, make sedimentary rock a crucial source of information about the nature and sequence of past environments on Earth.

Bedding, or stratification, is the arrangement of sediment particles into distinct layers (beds or strata) having different sediment compositions and/or grain sizes. A clear break, or

bedding plane, is generally visible between adjacent beds. Such bedding planes mark the end of one depositional event and the beginning of the next. For example, a flooding river often deposits a particle load of heavy, coarse-grained sediment on top of finer preexisting sediments in the surrounding area; such a difference in grain size would be visible as a bedding plane in a cross section of the resulting sediment layers (Fig.2.3).

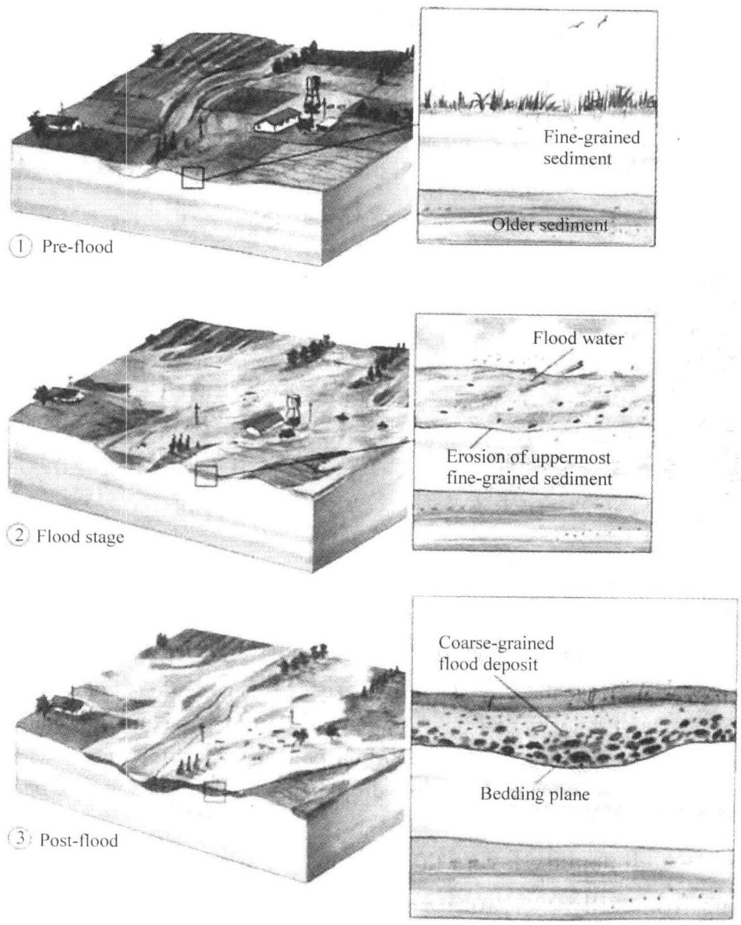


Figure 2.3 Development of a bedding plane due to river flooding
Any depositional event that leaves sediment that differs from the preexisting sediment (in terms of either grain size or composition) leaves a demarcation, a bedding plane, between the resulting sediment layers

When a sediment load containing a variety of sediment sizes is suddenly dumped into relatively still water, such as when a sediment-laden stream empties into a lake or ocean, its particles will settle at different rates, depending on their sizes, densities, and shapes. This gradual settling produces a graded bed, a single sediment layer (formed by a single depositional event) in which particle size varies gradually, with the coarsest particles found on the bottom and the finest at the top (Fig. 2.4). To demonstrate the principle of grading, drop a handful of unsorted backyard dirt into a tall glass of water. The largest particles will

quickly settle to the bottom, while the finest will settle last and land on top of the larger particles. Where graded beds exist, geologists can use them to determine whether tectonic forces have overturned the strata.

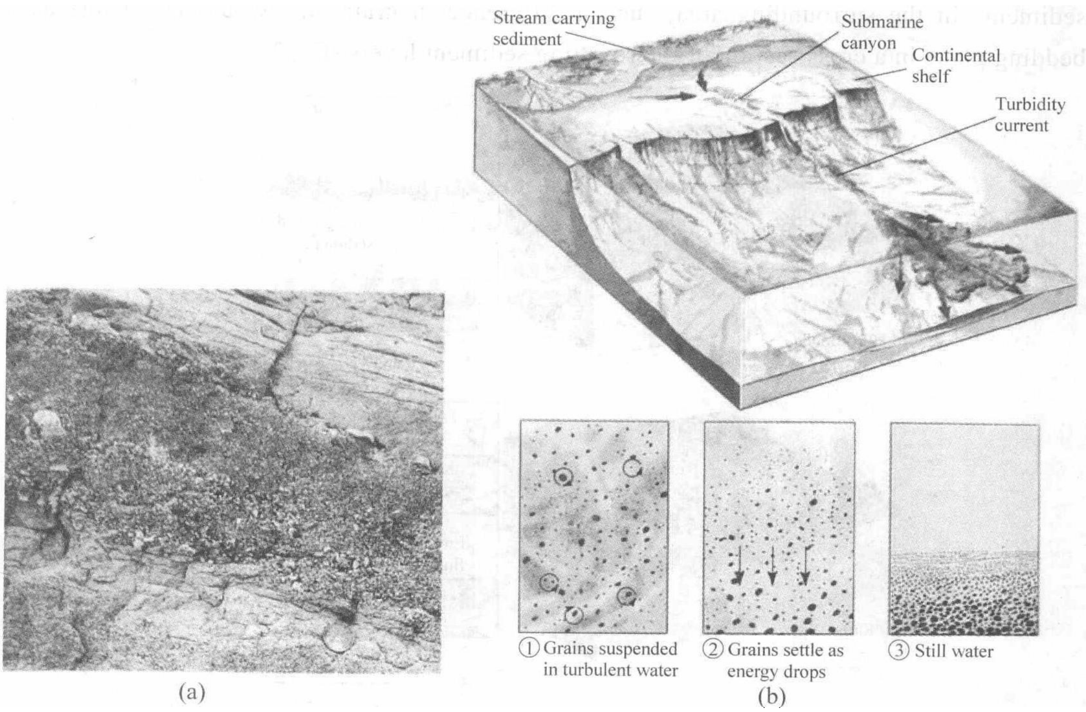


Figure 2.4 Graded bedding of sediment at Furnace Creek, Death Valley, California

(a) Graded beds form as particles of different density, size, and shape settle out of a standing body of water into distinct layers. The larger, heavier particles settle to the bottom first and the smaller, lighter particles settle above them. (b) Graded sediment is frequently produced by turbidity currents, offshore sediment flows that abruptly lose their energy and drop their particle loads onto the ocean floor

Cross-beds are sedimentary layers that, because they are deposited by a moving current instead of settling from still water, form at an angle to underlying beds. Cross-beds are often found in wind-deposited sand dunes and in water-deposited sediment at the bottom of a stream. Because cross-beds always slope toward the down-current direction, they record the flow direction of the current that deposited them.

New Words and Expressions

1.bedding ['bediŋ] *n.* 层理
2.stratification [ˌstrætifi'keiʃən] *n.* 层理，地层
3.bedding plane 层理面，层面
4.demarcation [ˌdiːmɑː'keiʃən] *n.* 界线，界限，分界
5.dump [dʌmp] *vt.* 倾倒，倾卸
6.graded bed 粒级层，递变层
7.at an angle 倾斜地，成一定角度
8.sand dune 沙丘

阅读材料

沉 积 岩

三、沉积岩的构造

沉积物通常具有在沉积过程中或沉积后不久所形成的沉积构造和物理特征，同时沉积物也反映了它形成时的沉积环境。这些构造迹象，以及存在的化石使沉积岩成为了解过去地球环境性质以及次序的一种至关重要的信息来源。

层理是不同沉积物成分和/或颗粒大小在一空间距（层面或岩层）上产生层状排列。一个明显的间断或层面，一般在相邻层之间是明显的。这种层面标志着一个沉积层的结束和下一个沉积层的开始。例如，泛滥的河流经常在附近区域细颗粒沉积物顶部沉积粗重的颗粒沉积物；在形成的沉积层横剖面层面间可以看到这种颗粒大小的差异(见图 2.3)。

当带有多种粒度的沉积物突然被倾卸到相对静止的水中时，例如夹有沉积物的溪流排入到湖泊或海洋中，沉积物颗粒以不同速度沉积，这取决于沉积物大小、密度和形状。这种逐步地沉积产生递变层，单一沉积层(由单独的沉积作用形成)层内颗粒大小逐渐变化，最粗颗粒位于底部，最细颗粒位于顶部(见图 2.4)。为演示递变规律，在盛水的高玻璃杯中撒一把没有分选的后院泥土。最大的颗粒很快沉到杯底，而最小的颗粒最后沉到稍大一些颗粒的顶部。在存在递变层的地区，地质学家可以用递变层确定构造作用力是否把地层倒转。

因为交错层是被运动流体而不是被静止水流沉积，所以交错层是与下覆层呈一定角度的沉积层。交错层经常出现在风积沙丘中和河底水积沉积物中。由于交错层总是向流体下方倾斜，因此交错层记录了流体的流向。

Unit 3

Text

Metamorphism Rocks

1 Conditions Promoting Metamorphism

A basic geologic principle states that rocks and their constituent minerals are most stable in the environment in which they form and least stable in markedly different environments. For example, as we have learned, feldspars formed by relatively high-temperature igneous processes rapidly break down (weather) chemically at the Earth's surface, an environment characterized by relatively low temperatures and low pressure. Their replacements, clay minerals, are more stable than the feldspars under surface conditions. But if the clays were placed in a new environment of higher temperature and pressure—for example, if they became buried beneath tens of kilometers of overlying sediments and heated to 600 ℃ — they would react to form new minerals, and perhaps even some feldspars, that would be stable under these new conditions.

Metamorphic rock is created when heat and pressure combine to break the bonds between some of the ions in all unstable mineral, allowing them to migrate to other site in the rock and rebond. This migration of ions, which usually occurs via fluids circulating through the rock, results in recrystallization of the mineral: If the ions rebond at different sites within the same mineral, the process produces a new, more stable form of the same mineral; if they rebond with other unstable minerals in the rock, it yields an entirely new set of more stable minerals. During recrystallization, minute grains in a fine-grained rock are usually replaced by an interlocking mosaic of large, visible grains.

Metamorphic processes never break all of the bonds in a rock's minerals—if all bonds were broken, the rock would melt to form magma (an igneous process). Instead, metamorphism occurs when heat and pressure exceed certain threshold levels, destabilizing the minerals in rocks, but do not reach the heights needed to cause melting.

1.1 Heat

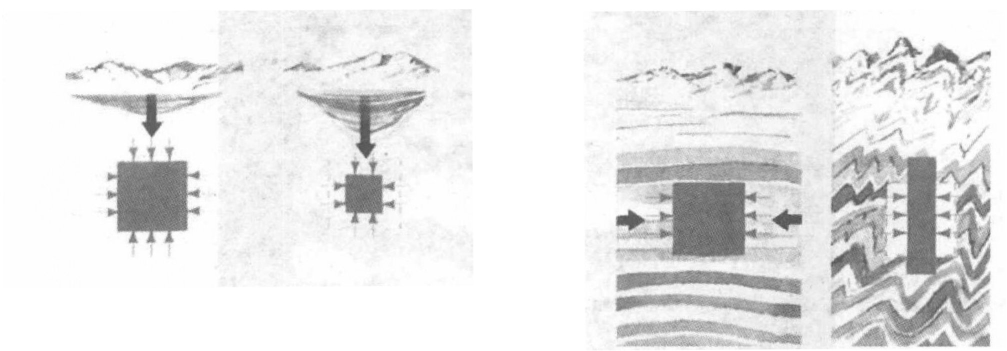
Heat, which speeds up the pace of nearly all chemical reactions, is perhaps the most important factor contributing to metamorphism. Metamorphism can sometimes occur in the absence of great pressure, but heat is usually necessary to initiate any significant chemical changes associated with metamorphism. Beneath the Earth's surface, temperature generally increases with depth due to the presence of radioactive isotopes, intruding magma, and

friction between moving bodies of rocks. Temperatures sufficient to metamorphose rocks—greater than about 200℃ are generally reached at a depth of about 10 km, a position still within the crust and upper mantle. Temperatures in this range may also occur nearer to the Earth's surface in rocks close to magmatic intrusions.

1.2 Pressure

Like heat, pressure increases with depth. The pressure required for metamorphism is more than 100 MPa, the prevailing pressure about 3 km beneath the Earth's surface. Metamorphism will not occur at this shallow a depth, however, unless heat is carried up from greater depths by magma or is induced by friction between tectonic plates.

When pressure is applied to a rock equally on all sides, as occurs at great depths, it is called lithostatic or confining pressure. When exposed to lithostatic pressure, a deeply buried rock becomes compressed into a smaller, denser form, but its shape remains the same (Fig. 3.1(a)). In some geologic settings, such as where tectonic plates collide to form mountains, pressure is applied principally in one plane, creating a force known as directed pressure. Directed pressure flattens and elongates a rock perpendicular to the direction of pressure (Fig. 3.1(b)). It may also deform individual components within the rock, such as fossils and mineral grains, causing them to become stretched and folded (Fig. 3.2).



Before Compression After Compression
Confining Pressure
(a)

Before Compression After Compression
Directed Pressure
(b)

Figure 3.1 Lithostatic versus directed pressure

(a) Deep burial of rocks generally subjects them to lithostatic, or confining pressure, an inward-pressing force that acts equally from all directions. A rock subjected to confining pressure becomes compressed without changing shape. (b) A rock subjected to directed pressure has its shape distorted, becoming thinner in the direction of the greatest pushing, or stress, and elongated in the direction perpendicular to the stress

Rocks subjected to either confining or directed pressure change in a number of ways. Both types of pressure close pore spaces between mineral grains, producing a more compact, denser rock. In addition, pressure at the contact points between compressed grains breaks some of their bonds, especially where water is present. The unbonded ions then migrate to lower-pressure sites, where they rebond.



Figure 3.2 Folded rock in the Blue Ridge Mountains of North Carolina
This example shows the deformation typical of rocks subjected to directed pressure

Directed pressure creates one special change in rocks: Recrystallized minerals develop a parallel alignment perpendicular to the directed pressure. This preferred alignment is known as foliation (Fig. 3.3). If the mineral grains are thin and planar, such as sheet-like mica flakes, their parallel orientation gives a distinctive layered look to the rock.

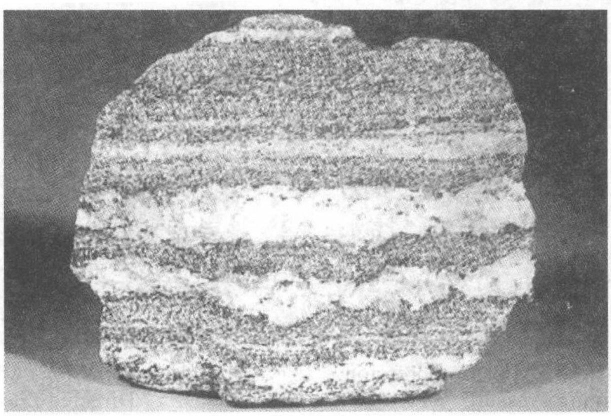


Figure 3.3 Pressure and foliation
Directed pressure creates foliation in rock

1.3 Circulating Fluids

Underground fluids, such as water and magmatic gases, enhance metamorphism by providing a medium through which unbonded ions can migrate among mineral grains. In addition, most such fluids contain a variety of ions derived from other rocks, which may be transferred to the rocks undergoing metamorphism. Thus fluids not only serve as the medium through which a rock's own unbonded ions migrate, but also contribute foreign ions to metamorphic reactions. As a result, the type of metamorphic rock that forms from a given parent rock depends on both the rock's original mineral content and, to some extent, on the

ion content of the fluids that flowed through it.

New Words and Expressions

1.metamorphism [ˌmetəˈmɔːfizəm] *n.* 变质，变质作用
2.markedly [mɑːktli] *adv.* 显著地，明显地
3.rebind [ˈriːˈbaind] *v.* 再胶结
4.via [ˈvaiə, ˈviːə] *prep.* 经，通过，经由
5.fine-grained [ˈfainˈgreind] *a.* 有细密纹理的
6.mosaic [mɔˈzeiik] *a.* 镶嵌状的
7.threshold [ˈθreʃhəuld] *n.* 临界(值)
8.destabilize [diːˈsteibilaiz] *vt.* 使动摇
9.isotope [ˈaisəutəup] *n.* 同位素
10.metamorphose [ˌmetəˈmɔːfəuz] *vt.* 使变形(质)
11.kilobar [ˈkiləubɑː] *n.* 千巴(气压单位)
12.prevailing [priˈveiliŋ] *a.* 占优势的，主要的
13.square centimeter 平方厘米
14.geologic setting 地质构造
15.flatten [ˈflætn] *v.* 变平，变单调
16.lithostatic [ˈlaiθəuˈstætik]*a.* 静岩的，岩石静压力的
17.confine [ˈkɔnfain] *vt.* 限制，禁闭
18.confining pressure 封闭压力，围压
19.elongate [ˈiːlɔŋgeit] *v.* 拉长，(使)伸长，延长
20.typical [ˈtipikəl] *a.* 典型的，标准的
21.alignment [əˈlainmənt] *n.* 准线，校正
22.foliation [ˌfəuliˈeiʃən] *n.* 叶理，剥理
23.leaflike [liːflaik] *a.* 像叶子的，成薄片的
24.planar [ˈpleinə] *a.* 平面的，平坦的
25.flake [fleik] *n.* 薄片
26.medium [ˈmiːdjəm] *n.* 介质，媒介物
27.transfer [trænsˈfəː] *v.* 传输、转移

变 质 岩

一、变质条件

基本地质定律认为：岩石及其矿物成分在生成环境中是非常稳定的，当环境显著改变时，会变得不稳定。例如，我们已知，在相对高温的火成岩过程中形成的长石，处于地表相对低温低压的环境中，发生迅速化学分解(风化)。取代长石的黏土矿物，在地表环境比长石更稳定。但如果黏土被置于高温高压的新环境中，例如，如果黏土被埋藏在千万米深的沉积物下，温度达 600 ℃，黏土将发生反应，形成新矿物，但在这种新环境下长石或许是稳定的。

当温度与压力联合作用破坏不稳定矿物中一些离子间的连接，使离子移动到岩石中的其他格位或重新胶结时，产生变质岩。通常在岩石内通过液体循环发生的这种离子移动使矿物重结晶：如果离子在同一矿物的不同晶格点处重新胶结，产生这种矿物更稳定的新形态；如果离子与岩石中其他不稳定矿物重新胶结，会产生一组更稳定的新矿物。在重结晶过程中，细颗粒岩石中的微小颗粒通常被肉眼可见的大颗粒连成的镶嵌体所代替。

变质过程不会破坏成岩矿物中所有的连接，如果所有的连接被破坏，岩石将熔化成岩浆(火成过程)。相反，温度和压力超过岩石中不稳定矿物的临界值，但并没有达到发生熔化的程度，变质作用就会发生。

(一)热

热，几乎会使所有化学反应速度加快，或许是控制变质作用最重要的因素。有时在

缺少高压情况下也可发生变质作用，但在发生与变质作用有关的显著化学变化时，通常开始温度是必不可少的。在地表以下，由于放射性同位素、侵入岩浆以及运动岩体间摩擦力的存在，温度通常随深度而增加。在地下大约 10 km 仍处于地壳和上地幔的深度处，一般可以达到使岩石发生变质的温度——远超过 200 ℃。在靠近地表与侵入岩浆邻近的岩石也可以达到这一温度范围。

(二)压力

与热一样，压力随深度而增加。发生变质作用的压力超过 100 MPa，在地表以下约 3 km 深度就会达到这一压力。然而，除非有深部岩浆带来的热或构造板块间摩擦力产生的热，否则在近地表处不会发生变质作用。

当压力被均等地施加到岩石的各个方向上，如同地下深部岩石受力状态，这种压力被称为静水压力状态或等围压状态。在静水压力作用下，深埋岩石被压缩成更小更密实的形态，但岩石形状保持不变(见图 3.1(a))。在一些地质环境中，例如，在构造板块碰撞形成山岳处，压力主要在一个平面内被施加，产生的力被称为定向压力。定向压力使垂直于压力方向的岩石变得扁平和拉长(见图 3.1(b))。定向压力也可以使岩石中的单一成分如化石和矿物颗粒伸长和褶皱(见图 3.2)。

受到围压或定向压力作用的岩石在形式上会发生多种变化。两种类型的压力都使矿物颗粒间的孔隙闭合，产生更加致密的岩石。另外，作用在被压缩颗粒接触点上的压力会破坏颗粒中的一些连接，尤其是有水存在的部位。这样未胶结的离子会移到较小的压力位置重新胶结。

定向压力在岩石内引起一种特殊变化：重结晶矿物垂直于定向压力平行排列。这种优势排列被称为叶理(见图 3.3)。如果矿物颗粒薄，并且是平面状的，如片状的云母薄片，矿物的平行定向使岩石具有独特的层状外观。

(三)循环流体

地下流体，如水和岩浆气体，由于提供的介质可使未胶结离子在矿物颗粒之间移动，促进了变质作用。另外，这种液体的大部分含有多种来源于其他岩石的离子，这些离子可以被转移到正发生变质的岩石中。因此，流体不仅可作为岩石本身未胶结离子迁移的介质，也有助于外来离子参与变质作用。因此，由母岩体形成的变质岩类型既取决于岩石的原生矿物成分，在某种程度上也取决于通过母岩流动的流体离子含量。

Reading Material

Metamorphism Rock

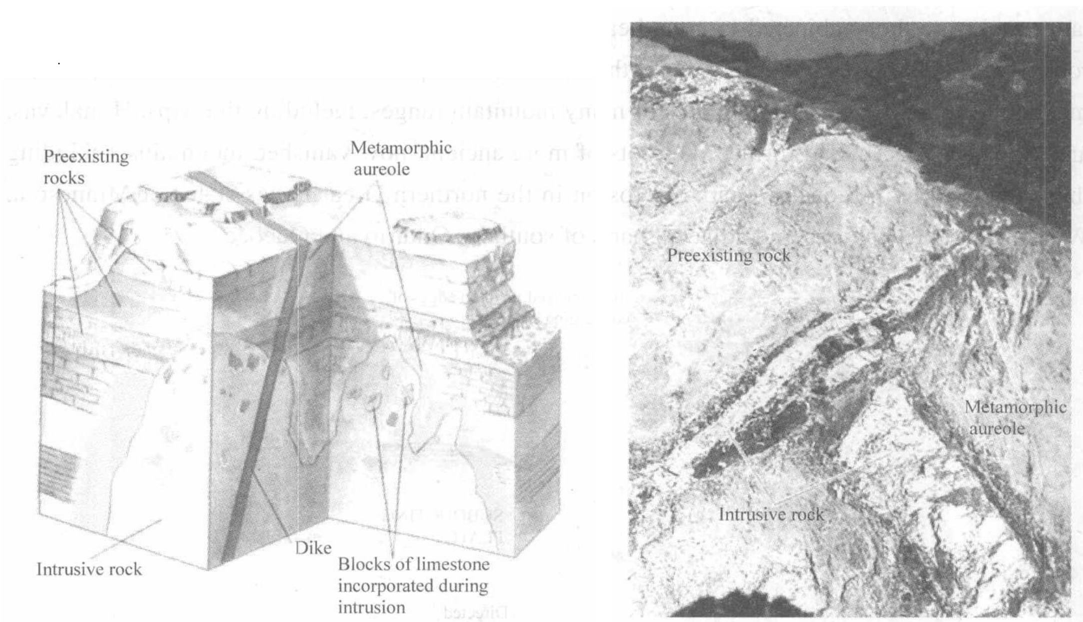
2 Types of Metamorphism

Heat, pressure, and chemically active fluids interact in different ways in different geological settings to produce metamorphic rocks. These settings therefore yield several distinctive types of metamorphism. Under some conditions, the metamorphic process affects

only a narrow area of rock; in other settings, rocks may be changed over a vast region.

2.1 Contact Metamorphism

Preexisting rock touched by the intense heat of migrating magma may undergo contact metamorphism. In this process, metamorphic change within the rock develops entirely from the heat from the magma and from hot circulating fluids; pressure is not a significant factor. Because most rocks are poor conductors of heat, the effect of contact metamorphism decreases with increasing distance from the magma. Rocks in direct contact with the intruding magma will be highly metamorphosed; those located farther away, which receive little magmatic heat, will be only slightly altered. The entire zone of contact metamorphism, referred to as a metamorphic aureole (Fig.3.4), may extend only a few centimeters or meters around a small igneous dike or sill, or it may extend up to several kilometers around a major batholith.



(a) (b)

Figure 3.4 Contact metamorphism

(a) Contact metamorphism occurs when magma intrudes preexisting rocks. The rocks adjacent to the magma become strongly metamorphosed; those father from the region of direct contact are less strongly affected, although they still receive metamorphic heat from circulating ion-rich fluids.
(b) An igneous dike in preexisting rock, with an obvious metamorphic aureole

2.2 Regional Metamorphism

Unlike contact metamorphism, which has relatively local effects, regional metamorphism alters rocks for thousands of square kilometers. For example, it created the vast regions of exposed metamorphic rock in central Canada and the tracts of metamorphic rock found in the Appalachians of New England, the Rockies, and the Cascades. Two types of regional

metamorphism are exist—burial metamorphism and dynamo-thermal metamorphism.

Burial metamorphism occurs when rocks are overlain by more than about 10 km of rock or sediment, and the confining pressure and geothermal heat at these depths combine to recrystallize their component minerals. Because the process does not involve directed pressure, burial metamorphic rocks are generally nonfoliated. Samples collected from deep drill boles show that burial metamorphism is occurring today in such locations as the Gulf Coast of Louisiana, where clay minerals lie beneath 12 km of sediment near the bottom of the Mississippi River's deltaic deposits.

Dynamo-thermal metamorphism occurs when rocks become caught between two converging plates during mountain building (Fig.3.5). In such a convergent plate setting, the lateral compression—a form of directed pressure—forces some rocks upward, forming mountains, and forces other rocks downward to depths of several to tens of kilometers. The latter rocks are then subjected to great heat and confining pressure. The resulting metamorphic rocks are typically foliated. Dynamo-thermal metamorphism created the vast regions of metamorphic rock that lie at the cores of many mountain ranges, including the Alps, Himalayas, and Appalachians. It also formed the roots of more ancient, now vanished mountains, including those exposed by billions of years of erosion in the northern Great Lakes states of Minnesota, Wisconsin, and Michigan and adjacent parts of southern Ontario and Quebec.

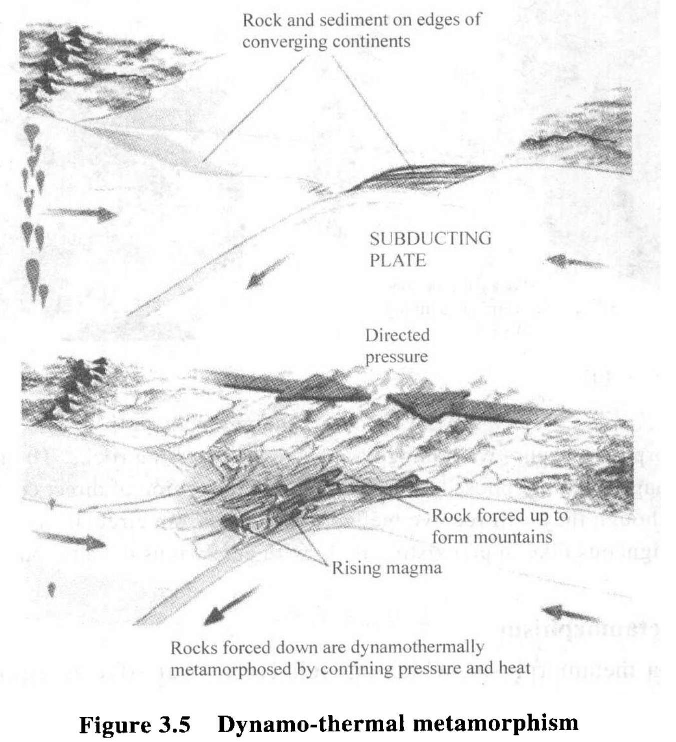


Figure 3.5 Dynamo-thermal metamorphism

This type of metamorphism is generally associated with the directed pressures and magmatic heat of convergent plate boundaries

2.3 Other Types of Metamorphism

Rocks may be metamorphosed in several ways other than by regional increases in heat and pressure or by contact with intruding hot magmas. Hydrothermal metamorphism is the chemical alteration of preexisting rocks by hot water. Most hydrothermal metamorphism occurs within ocean floors, when seawater penetrates cracks near a divergent plate boundary and becomes heated by hot magma. Rising back up through the rock as steam, it promotes the recrystallization of olivine and pyroxene in the oceanic basalt, converting them into the magnesium silicate serpentine. Fault metamorphism occurs as rocks grind past one another along a fault, thereby generating a large amount of directed pressure and considerable frictional heat. Shock metamorphism, a rare but dramatic type of metamorphism, results when a meteorite strikes the Earth's surface, generating tremendous pressures and extremely high temperatures. Some minerals created in a meteoric impact, such as stishovite, occur in no other geologic setting, and can thus be used to identify such sites long after erosion has removed any impression of a crater. Pyrometamorphism sometimes occurs where lightening bolts or burning subterranean coal seams subject rocks to intense heat.

New Words and Expressions

1.aureole ['ɔ:riəl] *n.* 接触变质带
2.dike [daik] *n.* 岩墙，岩脉
3.sill [sil] *n.* 基石，(地质)岩床
4.batholith ['bæθəliθ] *n.* 岩基
5.tract [trækt] *n.* 地区，区域，河段
6.dynamo-thermal ['dainəməu'θə:məl] *a.* 动热的
7.geothermal [ˌdʒi(:)əu'θəməl] *a.* 地热的，地温的
8.Gulf Coast 墨西哥湾岸区
9.Louisiana [lu(:)ˌi:zi'ænə] *n.* 路易斯安那，(美国南部的州名)
10.deltaic [del'teiik] *a.* 三角洲的，三角形的
11.convergent [kən'və:dʒənt] *a.*会聚性的，收敛的
12.core [kɔ:] *n.* 岩心，地核
13.root [ru:t] *n.* 根，根部
14.the Great Lake 大西洋
15.Minnesota [ˌmini'səutə] *n.* 明尼苏达州(美国州名)
16.Wisconsin [wis'kɔnsin] *n.* 威斯康星州(美国州名)
17.Michigan ['miʃigən] *n.* 密歇根州(美国州名)
18.Ontario [ɔn'tɛəriəu] *n.* 安大略湖
19.Quebec [kwi'bek] *n.* 魁北克(加拿大省名)
20.hydrothermal metamorphism 热液变质
21.divergent [dai'və:dʒənt] *a.* 扩张的
22.magnesium [mæg'ni:zjəm] *n.* 镁
23.silicate ['silikit] *n.* 硅酸盐
24.serpentine ['sə:pəntain] *n.* 蛇纹石，蛇纹石类，蛇纹岩
25.fault metamorphism 断层变质作用
26.shock metamorphism 震动变质作用
27.meteorite ['mi:tjərait] *n.* 陨星，陨石
28.meteoric [ˌmi:ti'ɔrik] *a.* 流星的，疾速的
29.stishovite ['stiʃəˌvait] *n.* 超石英(比重为4.2 的高压变体石英)
30.crater ['kreitə] *n.* 陨石坑
31.pyrometamorphism [ˌpaiərəuˌmetə'mɔ:fizəm] *n.* 高热变质
32.bolt [bəult] *n.* 雷电，螺栓
33.subterranean [sʌbtə'reiniən] *a.* 地球内的
34.seam [si:m] *n.* 矿层，煤层，层间薄层

阅读材料

变 质 岩

二、变质作用类型

温度、压力和化学活动性流体在不同的地质环境中以不同的方式相互作用产生变质岩。因此，这些环境产生一些独特的变质作用类型。在一些条件下，变质过程仅影响小范围内的岩石；在另外一些环境下，广阔区域内的岩石可以被变质。

(一)接触变质作用

与强烈高温流动岩浆相接触的已有岩石，可以发生接触变质作用。在这一过程中，岩石的变质完全由岩浆热量和热循环流体引起；压力不是一个重要的因素。由于大多数岩石是热的不良导体，接触变质作用的影响随着与岩浆距离的增加而降低。直接与侵入岩浆接触的岩石变质程度高；距离远一些的岩石接收岩浆热量很少，仅发生轻微变质。整个接触变质部分称为接触变质带(见图 3.4)，在小型的火成岩脉或岩床周围可能仅延伸几厘米或几米远，而在较大的岩基周围可能延伸几千米远。

(二)区域变质作用

不像接触变质作用那样仅有相对的局部影响，区域变质作用使上千平方公里内的岩石发生变质。例如，区域变质作用在加拿大中部形成广阔的变质岩出露区域，在新英格兰的 Appalachians、Rockies 和 Cascades 形成变质岩区域。有两种类型的区域变质作用存在：埋藏变质作用和热动力变质作用。

当岩石被大约 10 km 的岩石或沉积物覆盖时，发生埋藏变质作用，这一深度内的围压与地热共同作用使成岩矿物发生重结晶。因为重结晶过程中不存在定向压力，埋藏变质岩一般不存在叶理构造。从深部钻孔搜集的岩样显示，至今埋藏变质作用还在发生，如路易斯安那州的墨西哥湾岸区，在这里黏土矿物埋深达 12 km 即密西西比河三角洲沉积物底部。

在造山运动中，两收敛板块间的岩石变为捕虏体时，热动力变质作用就会发生(见图 3.5)。在这种收敛板块建造中，侧向挤压—— 一种定向压力——迫使一部分岩石上升形成山体，迫使另一部分岩石下降到几千米或几十千米的深度处。后者随后受到高温高压作用，使变质岩呈典型的叶理状。热动力变质作用在一个巨大的变质岩区域发生，包括 Alps、Himalayas 和 Appalachians 的核部形成广阔的变质岩区域。远古时期存在而现在已消失的山体，包括明尼苏达州北部的北美五大湖区、威斯康星州、密歇根州及南部安大略湖和魁北克相邻地区遭受数十亿年剥蚀的山体，山麓部分也是由热动力变质作用形成的。

(三)其他变质作用类型

岩石除了通过热、压力在区域上有所增加或者与高温侵入岩浆接触发生变质作用外，还可以通过其他几种方式变质。热液变质作用是通过热水作用使已存在的岩石发生化学变化。当海水渗入扩张板块边界附近的断裂时，被炽热岩浆加热，这样大部分热液变质作用会在海洋底板内发生。热液通过岩石缝隙以蒸气形式上升，促使海底玄武岩中橄榄石和辉石的重结

晶，将两种矿物转化成镁的硅酸盐类—— 蛇纹石。当岩石沿断层彼此相互研磨产生大量的定向压力和摩擦热时，发生断裂变质作用。当陨石撞击地球表面时，产生巨大压力和极高的温度，产生一种罕见且引人注目的变质作用—— 撞击变质作用。一些在陨石碰撞中产生的矿物，如超石英是在没有别的地质建造的环境下形成的，可以用来识别长期受剥蚀完全失去原貌的陨石坑位置。有时在雷电或燃烧的地下煤层处，岩石受到剧烈的高温作用，会发生高热变质作用。

Unit 4

Text

Folds

1 Folds

Folds are bends or wavelike features in layered rock. Folded rock can be compared to several layers of rugs or blankets that have been pushed into a series of arches and troughs. Often times folds in rock can be seen in roadcuts or other exposures (Fig. 4.1). When the arches and troughs of folds are concealed (or when they, exist on a grand scale), geologists can still determine the presence of folds by noticing repeated reversals in the direction of dip taken on outcrops in the field or shown on a geologic map.



Figure 4.1 Folded sedimentary rocks, Lulworth Cove, Dorset, England. Photo © Tom Bean

The fact that the rock is folded shows that it was strained in a ductile way rather than by elastic or brittle strain. Yet the rock exposed in outcrops is generally brittle and shatters when struck with a hammer. The rock is not metamorphosed (most metamorphic rock is intensely folded because it is plastic under the high pressure and temperature environment of deep burial and tectonic stresses). Perhaps folding took place when the rock was buried at a moderate depth where high confining pressure favors plastic behavior. Alternatively, folding could have taken place close to the surface under a very low rate of strain (When we strike a rock with a hammer, the strain rate is very high at the point of impact).

2 Geometry of Folds

Determining the geometry or shape of folds may have important economic implications because many oil and gas deposits and also some metallic mineral deposits are localized in folded rocks. The geometry of folds is also important in unraveling how a rock was strained and how it might be related to the movement of tectonic plates. Folds are usually associated with compressive stresses along convergent plate boundaries, but are also commonly formed where rock has been sheared along a fault.

Because folds are wavelike forms that usually form by the shortening of rock layers, two basic fold geometries are common—anticlines and synclines (Fig. 4.2).

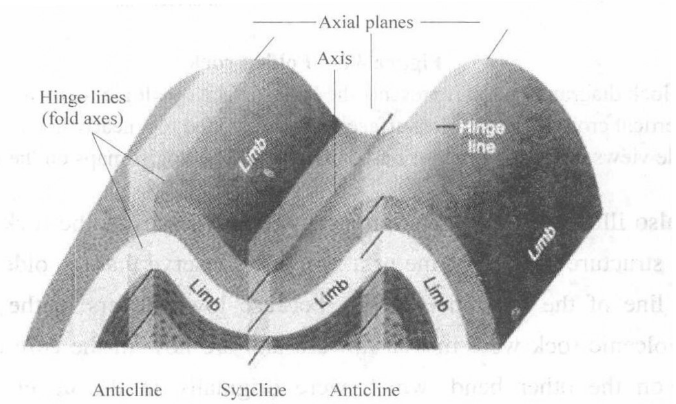


Figure 4.2 Diagrammatic sketch of two anticline and a syncline illustrating the axial planes, hinge lines, and fold limbs

An anticline is an upward arching fold. Usually the rock layers dip away from the hinge line (or axis) of the fold. The downward-arching counterpart of an anticline is a syncline, a troughlike fold. The layered rock usually dips toward the syncline's hinge line. In the series of folds shown in Figure 4.2. Two anticlines are separated by a syncline. Each anticline and adjacent syncline share a limb. Note the hinge lines on the crests of the two anticlines and bottom of the syncline. Similar hinge lines could be located in the hinge areas at the contacts between any two adjacent folded layers. For each anticline and the syncline, the hinge lines are contained within the shaded vertical planes. Each of these planes is an axial plane, an

imaginary plane containing all of the hinge lines of a fold. The axial plane divides the fold into its two limbs.

It is important to remember that anticlines are not necessarily related to ridges nor synclines to valleys, because valleys and ridges are nearly always erosional features. In an area that has been eroded to a plain, the presence of underlying anticlines and synclines is determined by the direction of dipping beds in exposed bedrock, as shown in Figure 4.3 (In the field, of course, the cross sections are not exposed to view as they are in the diagram).

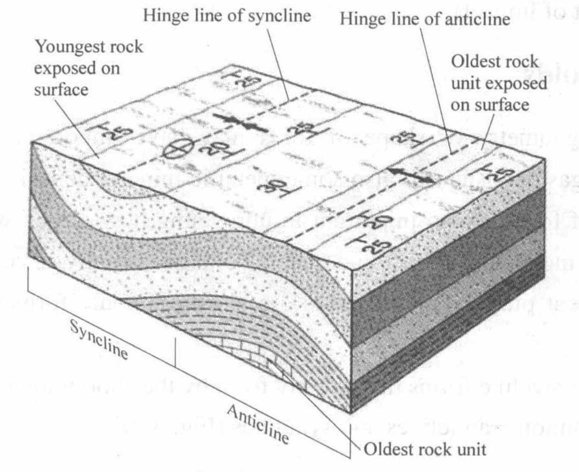


Figure 4.3 Folded rock

This view is a block diagram. Its top represents the land surface (geologic map) and its two visible sides are vertical cross sections. The surface has been eroded to a nearly horizontal plain. Side views are interpretations based on what the geologist maps on the surface

Figure 4.3 also illustrates how determining the relative ages of the rock layers, or beds, can tell us whether a structure is an anticline or a syncline. Observe that the oldest exposed rocks are along the hinge line of the anticline. This is because lower layers in the originally flat-lying sedimentary or volcanic rock were moved upward and are now in the core of the anticline. The youngest rocks, on the other band, which were originally in the upper layers, were folded downward and are now exposed along the synclinal hinge line.

2.1 Plunging Fold

The examples shown so far have been of folds with horizontal hinge lines. These are the easiest to visualize. In nature, however, anticlines and synclines are apt to be plunging folds—that is, folds in which the hinge lines are not horizontal. On a surface leveled by erosion, the patterns of exposed strata (beds) resemble Vs or horseshoes (Fig.4.4) rather than the striped patterns of nonplunging folds. However, plunging anticlines and synclines are distinguished from one another in the same way as are nonplunging folds—by directions of dip or by relative ages of beds.

A plunging syncline contains the youngest rocks in its center or core and the V or horseshoe

points in the direction, opposite of the plunge. Conversely, a plunging anticline contains the oldest rocks in its core and the V points in the same direction as the plunge of the fold.

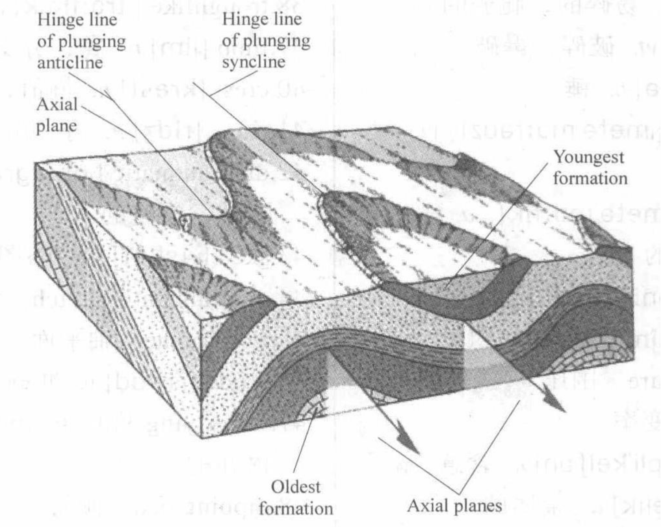


Figure 4.4 Plunging folds anticline on left and right, syncline in center
The hinge lines are at an angle to the block diagram, penetrating the surface and emerging from the front cross section

2.2 Structural Domes and Structural Basins

A structural dome is a structure in which the beds dip away from a central point. In cross section, a dome resembles an anticline and is sometimes called a doubly plunging anticline. In a structural basin, the beds dip toward a central point; in cross section, it is comparable to a syncline (doubly plunging syncline). A structural basin is like a set of nested bowls. If the set of bowls is turned upside down, it is analogous to a structural dome.

Domes and basins tend to be features on a grand scale (some are more than a hundred kilometers across), formed by uplift somewhat greater (for domes) or less (for basins) than that of the rest of a region. Michigan's lower peninsula and parts of adjoining states and Ontario are on a large structural basin. Domes of similar size are found in other parts of the Middle West. Smaller domes are found in the Rocky Mountains.

Domes and anticlines as well as some other structures are important to the world's petroleum resources.

New Words and Expressions

1.wavelike ['weivlaik] *a, adv.* 波浪般的(地)，波状的(地)
2.layered rock　层状岩石
3.rug [rʌg] *n.* (小)地毯，垫子
4.blanket ['blæŋkit] *n.* 覆盖层，毯子
5.arch [ɑ:tʃ] *n.* 拱，拱形物
6.trough ['trɔ:f] *n.* 断槽，地槽
7.grand [grænd] *a.* 重大的，主要的
8.reversal [ri'və:səl] *n.* 反转，反向
9.strain [strein] *v.* 拉紧，扯紧

10.ductile [ˈdʌktail] *a.* 延性的，黏性的
11.elastic [iˈlæstik] *a.* 弹性的
12.brittle [ˈbritl] *a.* 易碎的，脆弱的
13.shatter [ˈʃætə] *vt.* 破碎，爆破
14.hammer [ˈhæmə] *n.* 锤
15.metamorphose [ˌmetəˈmɔːfəuz] *vt.* 使变形[质]
16.metamorphic [ˌmetəˈmɔːfik] *a.* 变质的，改变结构的
17.tectonic [tekˈtɔnik] *a.* 构造的
18.confine [ˈkɔnfain] *v.* 限制，约束
19.confining pressure 围压
20.strain rate 应变率
21.implication [ˌimpliˈkeiʃən] *n.* 含意，暗示
22.metallic [miˈtælik] *a.* 金属的
23.unravel [ʌnˈrævəl] *vt.* 解开，拆开
24.tectonic plate 构造板块
25.compressive [kəmˈpresiv] *a.* 有压缩力的
26.compressive stress 压应力
27.convergent [kənˈvəːdʒənt] *a.* 会聚性的，收敛的
28.convergent plate boundary 会聚板块边界
29.shear [ʃiə] *v.* 剪切
30.fold geometry 褶皱的几何形态
31.anticline [ˈæntiˌklain] *n.* 背斜
32.syncline [ˈsiŋklain] *n.* 向斜
33.arching [ˈɑːtʃiŋ] *n.* 弓状结构，拱架
34.hinge [hindʒ] *n.* 铰链，枢纽
35.hinge line 枢纽线，铰合线
36.axis [ˈæksis] *n.* 轴
37.counterpart [ˈkauntəpɑːt] *n.* 副本，对应物
38.troughlike [ˈtrɔːflaik] *a.* 槽形的
39.limb [lim] *n.* 翼，分支
40.crest [krest] *n.* 巅值，峰值
41.ridge [ridʒ] *n.* 脊，山脊
42.diagrammatic [ˌdaiəgrəˈmætik] *a.* 图表的，概略的
43.sketch [sketʃ] *n.* 略图，草图
44.diagrammatic sketch 示意图
45.axial plane 轴平面
46.erode [iˈrəud] *v.* 冲刷，侵蚀
47.underlying [ˈʌndəˈlaiiŋ] *a.* 在下面的，潜在的
48.dipping bed 倾斜层
49.block diagram 方框图
50.side view 侧面图
51.plunging fold 倾伏褶皱
52.level [ˈlev(ə)l] *vi.* 变平，拉平
53.resemble [riˈzembl] *vt.* 像，类似
54.horseshoe [ˈhɔːsʃuː] *n.* 马蹄形
55.strip [strip] *n.* 条，带
56.penetrate [ˈpenitreit] *vt.* 穿透
57.dome [dəum] *n.* 穹窿
58.structural dome 构造穹窿
59.basin [ˈbeisn] *n.* 盆地
60.structural basin 构造盆地
61.nested [ˈnestid] *a.* 嵌套的
62.analogous [əˈnæləgəs] *a.* 类似的
63.uplift [ʌpˈlift] *n.* 上升，隆起，抬升
64.peninsula [piˈninsjulə] *n.* 半岛

褶 皱

一、褶皱

所谓褶皱是指岩层发生弯曲或起伏。可以把发生褶皱的岩石与叠在一起的垫子和毯子相比，它们在外力推挤下形成拱起和凹槽。有时可以在路堑或岩石出露的地方见到(见

图 4.1)。当褶皱的拱起和凹槽发生隐蔽(或当它们大范围存在时)，地质学家仍可以通过野外露头在倾向方向见到的重复倒转或地质图上见到的情况加以确定。

岩石褶皱的事实显示岩石发生韧性变形而不是弹性或脆性变形。一般，露头岩石具易碎性，锤击而坏。岩石没有变质(处于地下深处高压高温环境以及构造压力的作用下，岩石呈塑性，因此大多数变质岩发生强烈褶皱)。也许岩石埋藏深度适中时，高围压会使岩石表现为塑性，发生褶皱。另一方面，在近地表处低的应变率下也可能产生褶皱(当我们用锤敲击岩石时，在敲击点应变率是非常高的)。

二、褶皱的几何形态

由于许多石油、天然气矿床和一些金属矿床都储存在发生褶皱的岩石中，因此确定褶皱的几何形态或类型有重要的经济意义。褶皱的几何形态对于揭示岩石如何变形以及与地壳板块构造运动的关系也是非常重要的。褶皱通常与分布在板块边界的压应力有关，但在岩石沿断层发生剪切时也会形成褶皱。

由于褶皱通常是岩层收紧形成的波浪型，故常见两种基本的褶皱几何形状是：背斜和向斜(见图 4.2)。

背斜是向上拱起的褶皱。通常岩层都是从褶皱轴向外倾斜。背斜向下拱是向斜，呈槽型。层状岩石总是倾向于向斜的褶皱轴。如图 4.2 所示，两侧为背斜，中间为向斜。每个背斜和相邻的向斜有一个翼是共有的。注意两个背斜顶部和向斜底部的轴。任意两个相邻褶皱层之间连接区上都存在类似的轴。对于每个背斜和向斜，轴都被包含在阴影垂直面内。阴影垂直面就是轴面，它是一个包含整个褶皱轴的假想面。轴面把褶皱分为两个翼。

记住背斜不一定是山脊，向斜也不一定是山谷，因为山谷与山脊几乎都经受了侵蚀。在已被侵蚀成平原的地区，地下背斜和向斜的存在是根据出露岩石倾斜层的方向确定，如图 4.3 所示(当然，在野外横剖面不会像图中所见到的那样标准)。

图 4.3 还阐明了如何确定岩层或岩床的相对时代，这样可以告诉我们一个构造是背斜或是向斜。观察发现，年代最老的岩石露头会沿着背斜的轴线延伸。这是因为下部最初水平的沉积岩或火山岩向上弯曲，导致下部岩层位于背斜核部。而另一方面，最初在上面时代新的岩层向下弯曲，沿向斜的轴分布。

(一)倾伏褶皱

到目前为止所举的例子都是具有水平轴的褶皱。这些是最容易想象的。然而，在自然界背斜和向斜容易形成倾伏褶皱——也就是说，褶皱的轴不是水平的。由于侵蚀使表部呈水平状，出露地层(岩床)的形式类似 V 字形或马蹄形(见图 4.4)而不是非倾伏褶皱的条带形式。但倾伏背斜和向斜相互区别的方法与非倾伏褶皱相同——利用岩层的倾向或岩层的相对时代。

倾伏向斜的中心或核部岩石年代最新，V 字形或马蹄形是在倾伏相反方向时代最新。相反地，倾伏背斜的核部岩石年代最老，V 字形与倾伏褶皱情况相同。

(二)构造穹窿和构造盆地

构造穹窿是岩层从一个中心点向外倾斜的构造。在横剖面上，穹窿类似于背斜，有时被称为双倾伏背斜。在构造盆地中，岩层向中心点倾斜；从横剖面上看，可以把构造

盆地比作向斜(双向倾伏向斜)。构造盆地就像一套嵌套的碗。如果把这套碗倒置，它就类似于构造穹窿。

穹窿和盆地常是大面积区域(一些超过上百公里)的特征，与区域其他部分相比，这一地区抬升的多些(形成穹窿)或抬升的少些(形成盆地)。密歇根州低处的半岛和相邻几个州以及安大略湖就处在一个大的构造盆地。在中西部的其他地区发现类似大小的穹窿。在落基山脉还发现了相对较小的穹窿。

穹窿和背斜以及一些其他构造对于世界石油资源是非常重要的。

Reading Material

Geologic Maps and Field Methods

In an ideal situation, a geologist studying structures would be able to fly over an area and see the local and regional patterns of bedrock from above. Sometimes this is possible, but very often soil and vegetation conceal the bedrock. Therefore, geologists ordinarily use observations from a number of individual outcrops (exposures of bedrock at the surface) in determining the patterns of geologic structures. The characteristics of rock at each outcrop in an area are plotted on a map by means of appropriate symbols. With the data that can be collected, a geologist can make inferences about those parts of the area he or she can not observe. A geologic map, which uses standardized symbols and patterns to represent rock types and geologic structure, is typically produced from the field map for a given area. On such a map are plotted the type and distribution of rock units, the occurrence of structural feature (folds, faults, joints, etc.), ore deposits, and so forth. Sometimes surficial features, such as deposits by former glaciers, are included, but these may be shown separately on a different type of geologic map.

Anyone trained in the use of geologic map can gain considerable information about local geologic structure because standard symbols and terms are used on the maps and the accompanying reports. For example, the symbol ⊕ on a geologic map denotes horizontal bedding in an outcrop. Different colors and patterns on a geologic map represent distinct rock units.

1 Strike and Dip

According to the principle of original horizontality, sedimentary rock and some lava flows and ash falls are deposited as horizontal beds or strata. Where those originally horizontal rocks are found tilted, it indicates that tilting must have occurred after deposition and lithification(Fig. 4.5). Someone studying a geologic map of the area would want to know the extent and direction of tilting. By convention, this is determining by plotting the relationship between a surface of an inclined bed and an imaginary horizontal plane. You can understand the relationship by looking carefully at Figure 4.6,which represents sedimentary beds cropping out alongside a lake(the lake surface provides a convenient horizontal plane for this discussion).

Strike is the compass direction of a line formed by the intersection of an inclined plane with a horizontal plane. In this example, the inclined plane is a bedding plane. You can see from Figure 4.6 that the beds are striking from north to south. Customarily only the northerly direction (of the strike line) is given, so we simply say that beds strike north a certain number of degrees east or west (such as N50°E).

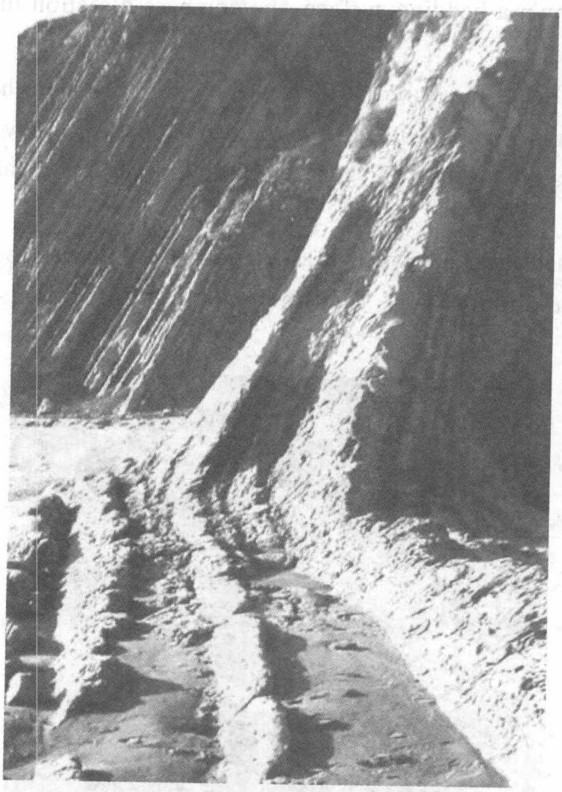


Figure 4.5 Tilted sedimentary beds along the coast of northern California near Pt. Arena
Here, the strike is the line formed by the intersection of the tilted sedimentary beds and the horizontal layer of sand in the foreground. The direction of dip is toward the left. Photo by Diane Carlson

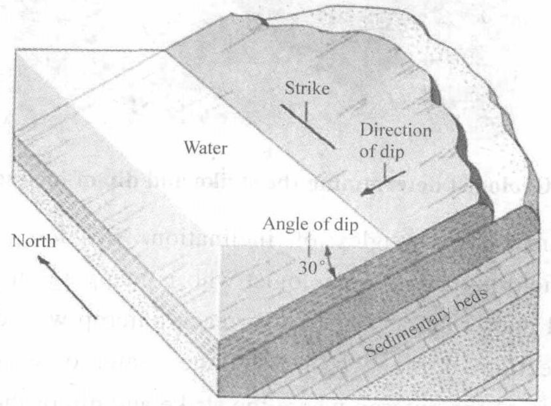


Figure 4.6 Strike, angle of dip, and direction of dip

Observe that the angle of dip is measured downward from the horizontal plane to the bedding plane (an inclined plane). Note that the angle of dip (30° in the Figure 4.6) is measured within a vertical plane that is perpendicular to both the bedding and the horizontal planes.

The direction of dip is the compass direction in which the angle of dip is measured. If you could roll a ball down a bedding surface, the compass direction in which the ball rolled would be the direction of dip.

The dip angle is always measured at a right angle to the strike, that is, perpendicular to the strike line as shown in Figure 4.6. Because the beds could dip away from the strike line in either of two possible directions, the general direction of dip is also specified—in this example, west.

A specially designed instrument called a Brunton pocket transit is used by geologists for measuring the strike and dip (Fig. 4.7). The Brunton pocket transit contains a compass, a level,

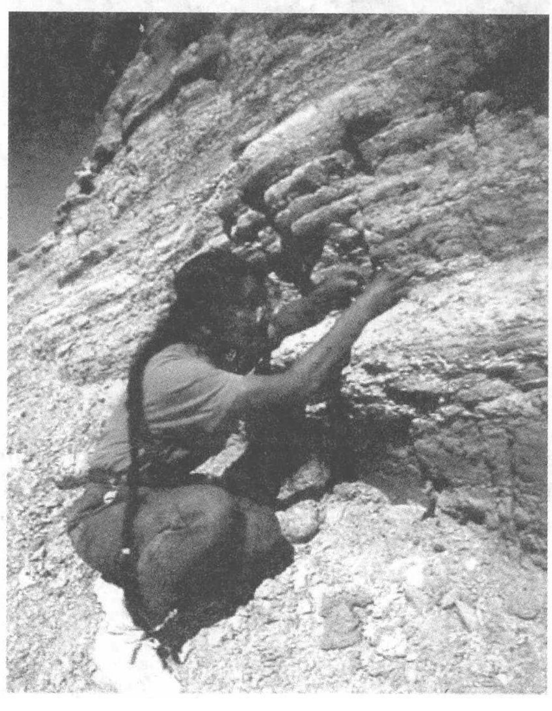


Figure 4.7 Geologist determining the strike and dip of inclined beds in Nevada

and a device for measuring angles of inclination. Besides recording strike and dip measurements in a field notebook, a geologist who is mapping an area draws strike and dip symbols on the field map, such as Y or 人 , for each outcrop with dipping or tilted beds. On the map, the intersection of the two lines at the center of each strike and dip symbol represents the location of the outcrop where the strike and dip of the bedrock were measured.

The long line of the symbol is aligned with the compass direction of the strike. The small tick, which is always drawn perpendicular to the strike line, is put on one side or the other, depending on which of the two directions the beds actually dip. The angle of dip is given as a number next to the appropriate symbol on the map. Thus, 25° ⅄ indicates that the bed is dipping 25°fom the horizontal toward the northwest and the strike is northeast (assuming that the top of the page is north). The orientation of the bed would be written N45°E, 25°NW. Figure 4.8 is a geologic map that shows all the sedimentary layers striking north and dipping 30°to the west (N0°,30°W).

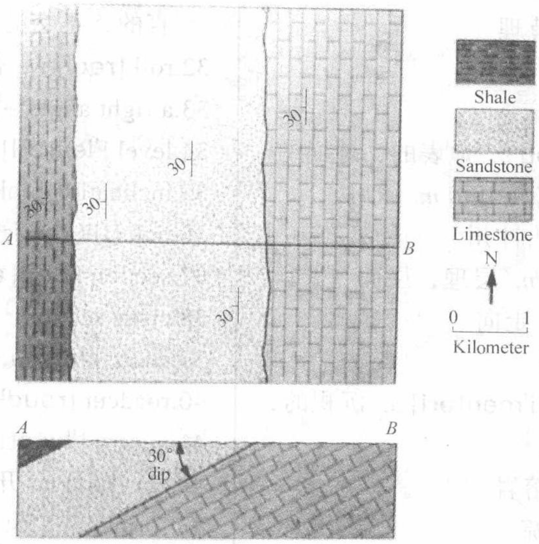


Figure 4.8 A geologic map and cross section of an area with three sedimentary formations (Each formation may contain individual sedimentary layers)

Beds strike north and dip 30° to the west. The geologic cross section (vertical cut) is constructed between points *A* and *B* on the map

Beds with vertical dip require a unique symbol because they dip neither to the left nor the right of the direction of strike. The symbol used is ⅄, which indicates that the beds are striking northeast and they are vertical (N45°, 90°).

2 Geologic Cross Sections

A geologic cross section represents a vertical slice through a portion of Earth. It is much like a roadcut or the wall of a quarry in that it shows the orientation of rock units and structures in the vertical dimension. Geologic cross sections are constructed from geologic maps by projecting the dip of rock units into the subsurface (Fig. 4.8), and are quite useful in helping visualize geology in three dimensions. They are used extensively throughout this book as well as in professional publications.

New Words and Expressions

1.bedrock ['bedrɔk] *n.* 基岩，岩床，底岩
2.vegetation [vedʒi'teiʃən] *n.* 植被
3.outcrop ['autkrɔp] *n.* 露头岩
4.exposure [iks'pəuʒə] *n.* 暴露，出露
5.rock unit 岩石地层单位
6.fold [fəuld] *n.* 褶皱
7.fault [fɔ:lt] *n.* 断层
8.joint [dʒɔint] *n.* 节理
9.ore [ɔ:(r)] *n.* 矿石
10.ore deposits 矿床
11.surficial [sə:'fiʃəl] *a.* 地表的，地面的
12.glacier ['glæsjə, 'gleiʃə] *n.* 冰川
13.former glacier 古冰川
14.bedding ['bediŋ] *n.* 层理，层面
15.strike [straik] *n.* 走向
16.dip [dip] *n.* 倾向
17.sedimentary [sedi'mentəri] *a.* 沉积的，由沉积物形成的
18.lava ['lɑ:və] *n.* 熔岩
19.lava flow 熔岩流
20.ash fall 灰尘沉降，火山灰沉降
21.strata ['streitə] *n.* 层，地层，岩层
22.tilted [tiltid] *a.* 倾斜的，翘起的
23.lithification [ˌliθifi'keiʃən] *n.* 成岩作用
24.by convention 按照惯例
25.incline [in'klain] *n.* 斜面，倾向，倾斜
26.inclined bed 倾斜层
27.crop out (岩石、矿石等)露在地面，显露出来
28.compass ['kʌmpəs] *n.* 罗盘，指南针
29.customarily ['kʌstəmərəli;ˌkʌstə'merəli] *adv.* 通常
30.northerly ['nɔ:ðəli] *a.* 北方的，来自北方的
31.perpendicular [ˌpə:pən'dikjulə] *a.* 垂直的，正交的
32.roll [rəul] *vt.* 使滚(转)动
33.a right angle 直角
34.level ['lev(ə)l] *n.* 水准仪
35.inclination [ˌinkli'neiʃən] *n.* 倾度，倾向
36.tick [tik] *n.* 记号，勾号
37.section ['sekʃən] *n.* 剖面
38.cross section 横剖面
39.slice [slais] *n.* 切片，薄片，分层
40.roadcut [rəudkʌt] *n.* 路堑
41.quarry ['kwɔri] *n.* 采石场，石坑
42.cut [kʌt] *n.* 开采
43.formation [fɔ:'meiʃən] *n.* 群，系
44.sedimentary formation 沉积岩层，沉积构造
45.construct [kən'strʌkt] *vt.* 绘(编)制，作(图)
46.subsurface [sʌb'sə:fis] *n.* 地表下的岩石(土壤)，水面下的水层
47.visualize ['vizjuəlaiz, 'viʒ-] *v.* 目测，设想，显象

阅读材料

地质制图与野外工作方法

在理想的情况下，研究构造的地质学家可以乘飞机飞过一个地区，从高空观察局部的和区域的基岩形式。有时这是可能的，但土壤和植被经常掩盖基岩。因此，地质学家一般通过观察大量单个岩层露头(地表基岩的出露部分)来确定地质构造形式。用适当的

符号把区域岩石露头的特征绘在图上。利用收集到的数据，地质学家对无法观察的那些地区进行推论。地质图是由所给定区域有代表性的野外地图上获得的，它采用标准的符号和模式表示岩石类型和地质构造。在这样的图上绘有岩石类型和分布、地质构造(褶皱、断层、节理)、矿床类型和分布情况。有时还包括地表特征，如古冰川沉积物，但这些可能会分开显示在另一种不同类型的地质图上。

由于地质图和相应的报告使用的是标准符号和术语，因此经过培训的任何人使用地质图能从中获得大量地质构造信息。例如，在地质图中符号 ⊕ 表示露头处的水平岩层。地质图上不同的颜色和符号代表不同的岩层单元。

一、走向和倾向

按照原始岩层开始为水平状这一准则，沉积岩和一些熔岩流、火山灰沉积时应呈水平层状或具层状层理。然而，在一些地方这些最初水平的岩石被发现是倾斜的，说明倾斜发生在沉积作用和成岩作用之后(见图 4.5)。研究一个地区地质图的人想知道岩层倾斜的范围和方向。按照惯例，这要通过绘制倾斜层面和想象的水平面之间的关系确定。你可以仔细观察图 4.6，理解这种关系，图中显示为湖相沉积岩层露头(在讨论时湖面认为水平)。

走向是倾斜平面和水平面交线罗盘指向。在这个例子中，倾斜面是岩层层面。你可以从图 4.6 看出，岩层的走向是自北向南。习惯上只给出(走向线)指向北的方向，因此我们简单地说岩层的走向是北偏东或偏西一定的角度(如 N50°E)。

通过观察发现，倾角是从水平面到层面(倾斜面)向下测量得到的角度。注意到倾角(图 4.6 中是 30°)是在一个与层面和水平面呈正交的垂直面中测量的。

倾向是测量倾角时的罗盘指向。如果你向着向下的层面滚动罗盘上的球珠，滚动球珠的罗盘方向就是倾向。

与走向成正交的方向上测量倾向，即如图 4.6 所示倾向正交于走向。因为岩层倾向可以与走向两个方向中的任一个有关，一般倾向也要说明——在这个例子中倾向西。

地质学家使用一种特别设计的仪器测量走向和倾向(见图 4.7)，该仪器被称为 Brunton 袖珍地质罗盘。Brunton 袖珍地质罗盘由指南针、水准仪和测量倾斜角度的装置组成。除了在野外笔记本上记录走向和倾向的测量结果外，进行区域填图的地质学家还要在野外草图上画出走向和倾向符号，如表示倾斜岩层露头或倾斜岩层的 ⅄ 或 ⅄ 。在地质图上，走向和倾向符号线的交汇点代表测量岩层露头的位置。符号的长线与罗盘走向方向一致。与长线垂直的短线画在长线的一侧或另一侧，这取决于岩层实际倾向。在图中倾角紧邻上述符号，以实测数字给出。这样，符号 $^{25°}$⅄ 表明岩层倾角 25°倾向北西，走向北东(假设该页面顶端指向正北)。岩层的方位可以写为 N45°E，25°NW。图 4.8 是一幅地质图，该图显示了图中所有沉积岩层走向为北、倾角 30°倾向西(N0°，30°W)。

垂直倾向的岩层需要一个特殊的符号，因为相对于走向它们既不向左倾斜也不向右倾斜。它所使用的符号是 ⺦，表明岩层走向为北东并且直立(N45°E，90°)。

二、地质剖面图

地质剖面图是通过一部分地层的垂直切面。它更像路堑或采石场墙，在这样的横剖面上显示了岩石地层单元的方位和垂直范围上的结构。地质横剖面图是通过地质图来绘制，即将地层单元在倾向方向上从地表到地下绘到剖面上(见图 4.8)，对于在三维空间想象地质情况是非常有帮助的。在这本书以及专业出版物中广泛使用横剖面图。

Unit 5

Text

Rock and Weathering

1 Weathering: The Breakdown of Rocks

Much of the Earth's most spectacular and unique scenery has been created by quite ordinary environmental factors acting upon rock. These factors, which act constantly and everywhere on Earth, remove or alter individual mineral grains in rock, yielding end products that look much different from the original rocks. The processes by which environmental agents at or near the Earth's surface cause rocks and minerals to break down is called weathering. Weathering is a slow but potent force to which even the hardest rocks are susceptible.

Rocks that have been weakened by weathering are more vulnerable to erosion, the process by which gravity, moving water, wind, or ice transports pieces of rock and deposits them elsewhere. The fragments removed from rock by erosion have usually been loosened by weathering, although a high-energy erosive event, such as a flood, may dislodge even unweathered rock. Like many geological processes, weathering and erosion are interrelated and often work in tandem. Together, they produce sediment, the loose, fragmented surface material that serves as the raw material for sedimentary rock.

Weathering plays a vital role in our daily lives, with both positive and negative outcomes. It frees life-sustaining minerals and elements from solid rock, allowing them to be come incorporated into our soils and finally into our foods. Indeed, we would have very little food without weathering, as this process produces the very soil in which much of our food is grown. But weathering can also wreak havoc on the structures we build. Countless monuments—from the pyramids of Egypt to ordinary tombstones—have suffered drastic deterioration from freezing water, hot sunshine, and other climatic forces.

2 Weathering Processes

Rocks can be weathered in two ways. Mechanical weathering breaks a mineral or rock into smaller pieces, but does not change its chemical makeup. Changes induced by mechanical weathering affect physical characteristics, such as the size and shape of the weathered structure. Chemical weathering changes the chemical composition of minerals and

rocks that are unstable at the Earth's surface (decomposes them), converting them into more stable substances; minerals and rocks that are chemically stable at the Earth's surface are resistant to chemical weathering.

Mechanical and chemical weathering take place constantly and simultaneously in most environments. Mechanical weathering renders rocks more susceptible to chemical weathering by making more surface area available for chemical attack, much as crushing a sugar cube with a spoon causes it to dissolve more rapidly in hot water. By mechanically disintegrating the sugar cube, you vastly increase its surface area; crystal surfaces previously hidden inside the larger cube therefore become exposed to the hot water. Similarly, the area of a boulder that is vulnerable to weathering agents consists only of its outer surface until mechanical weathering increases its surface area (Fig.5.1).

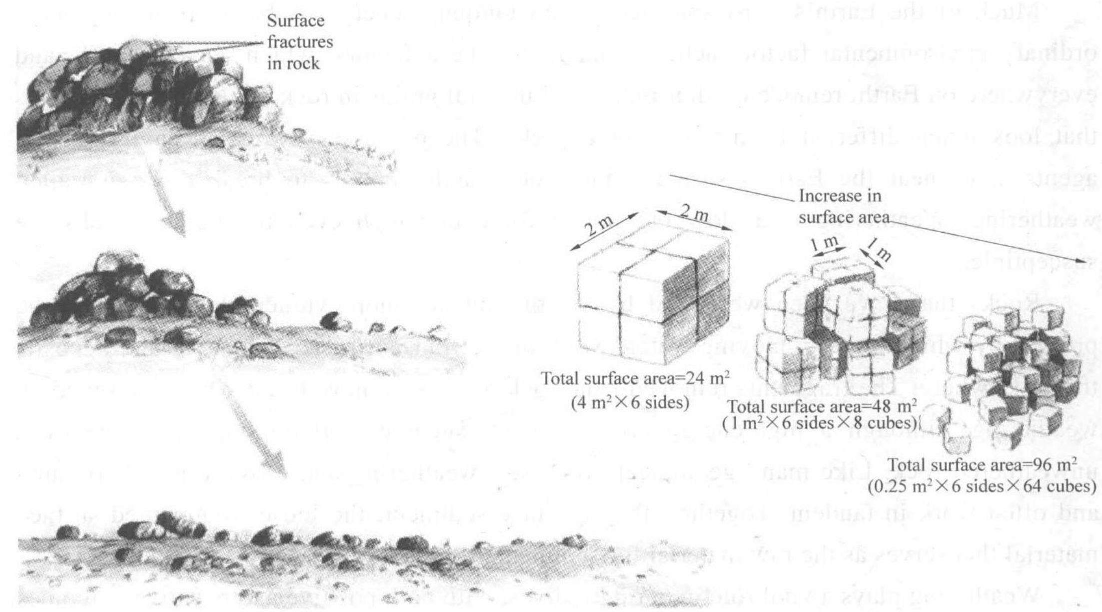


Figure 5.1 Mechanical weathering

This type of weathering breaks rocks and minerals into fragments, increasing the total surface area exposed to the processes of chemical weathering

2.1 Mechanical Weathering

A number of natural processes reduce rocks to smaller sizes without changing their chemical makeup. In any given location, several of these processes may be working at the same time.

Frost Wedging Water expands in volume by about 9% when it turns to ice. When water enters pores or cracks in a rock and then the temperature falls below 0°C (the freezing point of water), the force of the expanding ice greatly exceeds that needed to fracture even solid granite. As a result, the cracks become enlarged, often loosening or dislodging

fragments of rock (Fig.5.2). This enlargement allows even more water to enter the crack, and the process repeats. This process, called frost wedging, is the fastest, most effective type of mechanical weathering. It is most active in environments where surface water is abundant and temperatures often fluctuate around the freezing point of water.

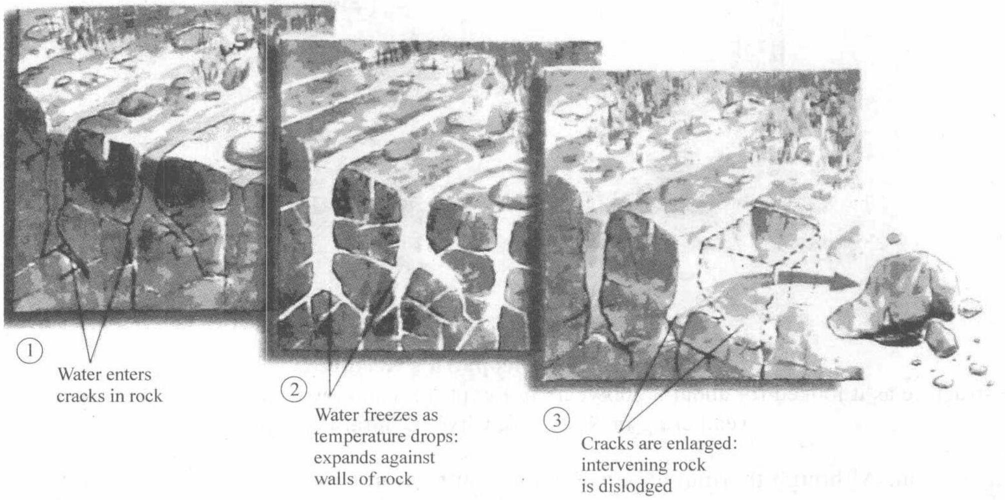
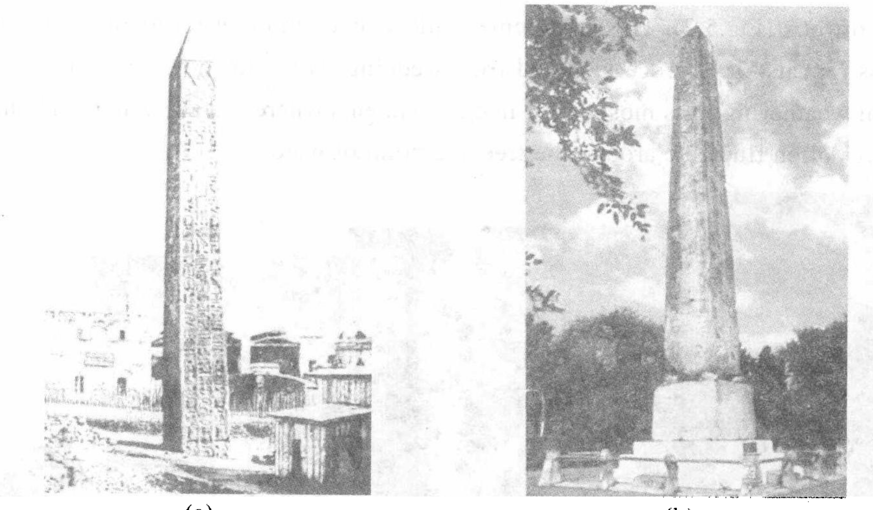


Figure 5.2 Frost wedging

In this type of mechanical weathering, water freezes and expands within cracks in rock, enlarging them. The cracks get bigger with each frost and may eventually dislodge intervening pieces of rock

Crystal Growth Along rocky shores, where salty sea spray soaks into rocks and evaporates, it leaves behind growing salt crystals within cavities in the rocks. The growth of the crystals applies great pressure to the walls of the cavities, prying them farther apart. This process has significantly damaged not only rocks, but also some well-known stone structures. Among them is Cleopatra's Needle, a granite obelisk that stood for more than 3 500 years in Egypt without much loss of the finely engraved hieroglyphics on its sides; when the obelisk was relocated to New York City, salt crystals that had already infiltrated small cracks in the needle absorbed water from the humid air and expanded, accelerating its weathering (Fig.5.3).

Thermal Expansion and Contraction If you have ever sat around a campfire, you may have noticed that thin layers of rock material tend to fall off the cracked surfaces of rocks close to the fire. This deterioration occurs because of thermal expansion, the enlargement of a mineral's crystal structure in response to heat. Each of the different minerals within a rock expands to a different degree when heated. For example, quartz grains expand about three times as much as grains of plagioclase feldspar that are exposed to the same heat. If a rock that contains both minerals becomes heated, the expanding quartz grains will push against neighboring feldspar grains, loosening and eventually dislodging them. Rocks, however, are poor conductors of heat. Heat does not penetrate very deeply or very quickly into the rock; instead, the heated outer portion of a rock tends to break away from the cool



(a) (b)

Figure 5.3 Cleopatra's Needle

The structure as it looked for about 3 500 years in Egypt (a), and how it looks today, after a century of weathering in New York City's Central Park (b)

inner portion. Although thermal expansion and contraction generally works extremely slowly, in regions such as deserts, where rocks are exposed to high daytime and low nighttime temperatures, it may cause a significant amount of weathering over long periods of time.

Mechanical Exfoliation When erosion of overlying rock or soil exposes a wide area of a large plutonic mass, pressure on the mass is reduced and it expands; because most of the structure remains underground, where surrounding rock continues to exert pressure on it, it expands upward. As the rock expands, it fractures into sheets parallel to its exposed surface. These sheets may then break loose and fall from the sloping surface of the structure, a weathering process known as mechanical exfoliation. Many mountains exhibit a dramatic "stepped" appearance because large slabs of rock, several meters in thickness, have exfoliated from underlying rocks (Fig. 5.4).

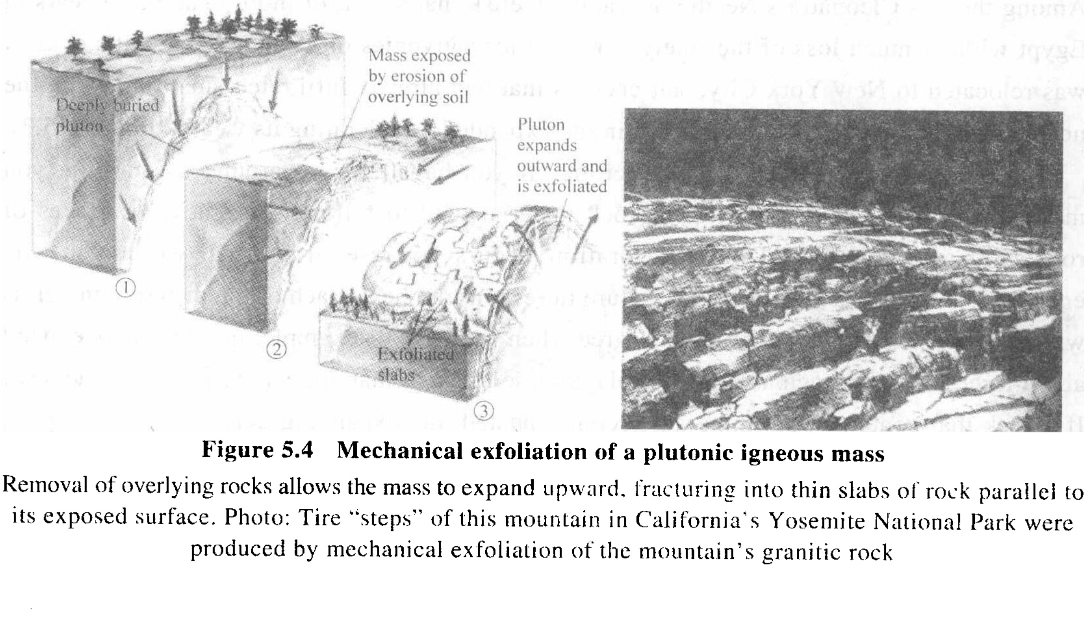


Figure 5.4 Mechanical exfoliation of a plutonic igneous mass

Removal of overlying rocks allows the mass to expand upward, fracturing into thin slabs of rock parallel to its exposed surface. Photo: Tire "steps" of this mountain in California's Yosemite National Park were produced by mechanical exfoliation of the mountain's granitic rock

New Words and Expressions

1.weathering ['weðəriŋ] *n.* 风化作用
2.breakdown ['breikdaun] *n.* 破坏，崩溃
3.spectacular [spek'tækjulə] *a.* 引人入胜的，壮观的
4.end product 最后产物
5.individual mineral 单个矿物，单矿物
6.agent ['eidʒənt] *n.* 营力，作用力
7.potent ['pəutənt] *a.* 有力的，有效的
8.susceptible [sə'septəbl] *a.* 易受影响的
9.vulnerable ['vʌlnərəb(ə)l] *a.* 易受攻击的，易受……的攻击
10.erosion [i'rəuʒən] *n.* 侵蚀(作用)
11.elsewhere ['els'hwεə] *adv.* 在别处
12.dislodge [dis'lɔdʒ] *vt.* 移出，移走
13.interrelate [ˌintə(ː)ri'leit] *v.* (使)相互关联
14.tandem ['tændəm] *adv.* 一前一后
15.incorporate [in'kɔːpəreit] *vi.* 合并，混合
16.wreak [riːk] *v.* 施加，造成
17.havoc ['hævək] *n.* 大破坏，毁坏
18.monument ['mɔnjumənt] *n.* 纪念碑
19.tombstone ['tuːmstəun] *n.* 墓石，墓碑
20.drastic ['dræstik] *a.* 激烈的，猛烈的
21.deteriorate [di'tiəriəreit] *v.* 使恶化，弄坏
22.disintegrate [dis'intigreit] *vt.* (使)分解，(使)碎裂
23.induce [in'djuːs] *vt.* 促使，导致，引起
24.decompose [ˌdiːkəm'pəuz] *v.* 分解
25.resistant [ri'zistənt] *a.* 抵抗的，有抵抗力的
26.chemical attack 化学侵蚀
27.crush [krʌʃ] *vt.* 压碎，碾碎
28.spoon [spuːn] *n.* 匙，调羹，勺子
29.boulder ['bəuldə] *n.* 巨砾，漂砾
30.frost [frɔst, frɔːst] *n.* 霜，霜冻
31.wedge [wedʒ] *vt.* 楔入，楔进
32.freezing point 凝固点，凝固温度
33.fracture ['fræktʃə] *v.* (使)破碎，(使)破裂
34.spray [sprei] *n.* 浪花
35.soak [səuk] *v.* 浸，泡，浸透
36.pry [prai] *vt.*(用工具)撬起，撬开，撬动
37.obelisk ['ɔbilisk] *n.* (埃及的)方尖塔(碑)，方尖碑形物
38.hieroglyphic [ˌhaiərə'glifik] *n.* (*pl.*) 象形文字
39.infiltrate [in'filtreit] *v.* 渗透，渗入
40.campfire ['kæmp ˌfair] *n.* 营火，户外营地里的火
41.plagioclase ['pleidʒiəukleis] *n.* 斜长岩
42.exfoliation [eksˌfəuli'eiʃən] *n.* 页状剥落
43.surrounding rock 围岩
44.slab [slæb] *n.* 厚平板，厚片

岩石与风化

一、风化作用：岩石的破坏

地球上大部分非常壮观和独特的风景是由作用在岩石上十分普通的环境因素形成的。这些因素时时处处在地球上发挥着作用，移动或改变岩石中的矿物，产生看起来与原始岩石完全不同的最终产物。环境营力在地表或接近地表处引起岩石或矿物破坏的过程被称为风化作用。风化作用是一种缓慢但有效的作用力，即使最坚硬的岩石也易受到影响。

受到风化变弱的岩石更容易侵蚀，这个过程是重力、流水、风或冰搬运岩块，并将其沉积到其他地方。虽然具有高能量的侵蚀作用，如洪水可以移走甚至未被风化的岩石，

但受到剥蚀岩石的移动碎片常因风化变松散。像许多其他地质过程一样，风化作用与侵蚀作用是相互关联的，经常一前一后发生作用。这两种作用一起产生了沉积物，即疏松的地表碎屑物，并成为沉积岩原始材料来源。

风化作用在我们的日常生活中扮演着至关重要的角色，既有积极的影响又有消极的后果。风化作用从固体岩石中释放了生命所必需的矿物和元素，使这些物质混合进入到土壤中，最终进入到我们的食物中。事实上，没有风化作用我们将几乎得不到食物，正由于这一过程才产生了我们许多食物生长的各种土壤。但风化作用也对建筑物造成毁坏。数不清的纪念碑——从埃及的金字塔到平常的墓碑——都遭受了冰水、灼热的阳光以及其他气候营力的剧烈破坏。

二、风化过程

岩石以两种方式被风化。机械风化将矿物或岩石破碎为更小的部分但并没有改变物质的化学组成。机械风化引起的变化影响物理特性，如受风化的结构大小和形状。化学风化改变地表不稳定矿物和岩石的化学成分(分解它们)，转化成更稳定的物质；地表化学性质稳定的矿物和岩石能抵抗化学风化。

在大多数环境中，机械风化和化学风化经常同时发生。机械风化产生更多的可被化学侵蚀的表面积，使岩石更容易遭受化学风化，非常像用匙压碎糖块后，糖在热水中溶解更快一样。机械破碎糖块，你大量增加了它的表面积；先前隐藏在较大立方体内的晶面因此暴露在热水中。类似地，巨砾易受到风化营力作用的面积仅是其外表面，机械风化会增加它的表面积(见图 5.1)。

(一)机械风化

在没有改变化学成分的情况下，许多的自然过程会减小岩石尺寸。在给定区域上，这些过程可能同时会发挥作用。

冰楔作用　水结成冰后体积膨胀大约 9%。水进入岩石中的孔隙或裂隙后，温度降低到 0℃以下(水的冰点)，冰膨胀产生的力远超过裂纹破坏所承受的力，甚至对花岗岩也如此。结果，裂隙变大，经常使岩石碎片松动或脱落(见图 5.2)。裂纹进一步扩大使更多的水进入裂隙，由此重复下去。这一过程，被称为冰楔作用，是最快、最有效的机械风化形式。在地表水丰富、温度在冰点左右常常发生波动的环境中，冰楔作用非常活跃。

晶体生长　沿石质海岸边线，含盐的海水浸泡岩石并蒸发，这样在岩石孔洞内会留下生长的盐晶体。晶体的生长对孔壁施加很大的压力，挤压孔壁，使其变宽。这一过程不但显著破坏岩石，也极大地破坏了一些很好的岩石结构。Cleopatra 石柱就是一例，它是已矗立在埃及有 3 500 多年的花岗岩塔形物，石柱侧面精美雕刻的象形文字保存完好；当石柱被重新安置在纽约后，渗入到石柱小裂隙内的盐晶体从潮湿的空气中吸收水膨胀，加速了石柱的风化(见图 5.3)。

热胀冷缩　如果你曾坐在营火旁，你可能注意到靠近火一侧岩石中的薄层趋向于沿裂隙面脱落。由于热膨胀产生这种破坏，热导致矿物晶体结构扩大。当受热时，岩石中的不同矿物膨胀程度不一。例如，在相同的受热条件下，石英颗粒的膨胀量是斜长岩颗粒膨胀量的 3 倍。如果含有这两种矿物的岩石受热，膨胀的石英颗粒将推挤相邻的长石

颗粒，松动并最终移动长石颗粒。然而，岩石是热的不良导体。热不能传到岩石深处或很快地传入岩石内部；相反，外部受热的岩石会在与内部温度低的岩石间发生剥落。虽然一般热胀冷缩作用极其缓慢，但在像沙漠这样的地区，岩石暴露在白天的高温和夜间的低温下，长时间热胀冷缩作用可以产生显著的风化效果。

机械剥落 当上覆岩石或土受侵蚀后，深部巨大火成岩体在广阔区域上被暴露，岩体上的压力减少，岩体膨胀；因为火成岩体大部分位于地下，围岩继续对地下火成岩体施加压力，岩体向上膨胀。由于岩体膨胀，岩体破裂成平行于其暴露面的薄片。这些薄片随后可能松动，沿火成岩体的倾斜面脱落，这就称为机械剥落的风化过程。因为岩石巨大的片层，厚度达几米，从下覆岩石上剥落，所以许多山体呈现出显著的 “阶梯” 状形态(见图 5.4)。

Reading Material

Rock and Weathering

2.2 Other Mechanical Weathering Processes

Almost all rocks contain some cracks and crevices. Plants and trees may take root in such cracks in surface rocks. Although rock would seem strong enough to withstand it, the force applied to a crack by a growing tree root is surprisingly powerful and quite capable of enlarging the crack. The buckled and broken sidewalks of some tree-lined boulevards convincingly demonstrate the weathering ability of such root growth.

Animals also contribute to mechanical weathering. For example, larger animals may step on stones or pebbles and crush them into smaller particles. Some birds ingest stones, which are used as grinding tools in their digestive processes and eventually released when worn down in size. The cumulative activities of even very small creatures, such as earthworms and insects, can also help break rocks into smaller fragments.

Mechanical weathering by abrasion occurs when rocks and minerals collide during transport or when loose transported material scrapes across the exposed surfaces of stationary rock. For example, sediment fragments carried in swirling streams or by gusty winds collide and grind against both each other and other rock surfaces, breaking into smaller particles. Similarly, rocks carried along at the base of a glacier scrape against underlying rocks and are ground to even smaller sizes.

2.3 Chemical Weathering

Chemical weathering alters the composition of minerals and rocks, principally through reactions involving water. Water is the single most important factor controlling the rate of chemical weathering, because it carries ions to the reaction site, participates in the reaction, and then carries away the products of the reaction. Rocks weather chemically by three major processes: dissolution, oxidation, and hydrolysis.

Dissolution In dissolution, ions or ion groups from a mineral or rock are removed and carried away by water. As we learned from chapter and section, water molecules can dissolve minerals by attracting and removing charged ions from the surfaces of the minerals. For example, dissolution of halite (NaCl) occurs when the positive sides of water molecules attract and dislodge chloride ions (Cl^-) and the negative sides of water molecules attract and dislodge sodium ions (Na^+).

Some mineral deposits, such as those containing gypsum or halite, are readily dissolved by water. In many cases, however, water itself does not remove ions from a mineral or rock, but rather reacts with another compound in the environment to form a substance—usually an acid—that does. This reaction most commonly involves the reaction of water with carbon dioxide (CO_2) to form carbonic acid (H_2CO_3).Carbonic acid, in turn, reacts with and dissolves limestone. Most of the world's caves were created by this process (Fig. 5.5).

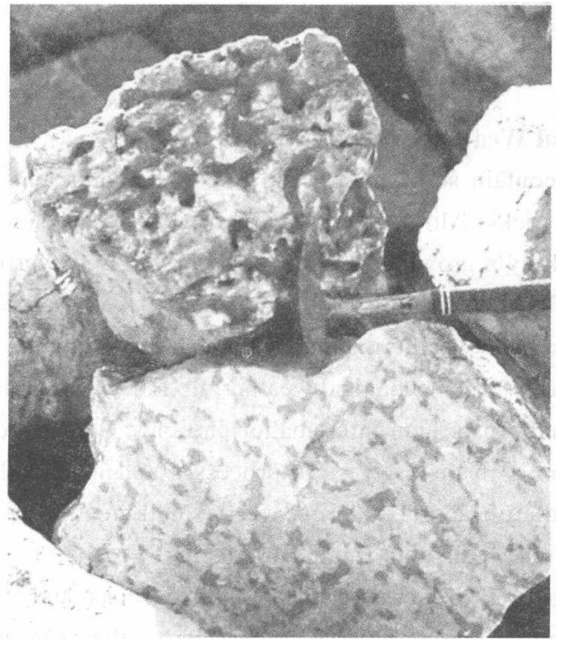


Figure 5.5 Weathered and unweathered limestone boulders

In humid environments, such as those in most southeastern states, limestone dissolves extensively along cracks and crevices, leaving behind thousands of cavities that range from minor surface depressions to large underground cave systems. In this photo, the limestone boulder above the hammer is weathered; the one below is not

Ions that have been removed from a rock or mineral by water and then carried away in the water are said to be in solution. When the water eventually evaporates, these substances remain behind and are said to have precipitated from the solution. As we will see in chapter and section, such precipitated materials represent an important kind of sediment and produce many sedimentary rocks.

Oxidation In oxidation, a mineral's ions combine with oxygen ions. For example, when iron ions (Fe^{2+}) in mafic rocks bond with oxygen in the atmosphere, they form the iron oxide Fe_2O_3 (hematite). Other iron oxides, such as yellowbrown goethite and yellowish limonite, form whenever iron-rich minerals and rocks come into contact with water. Iron oxides, commonly called rust, may stain the surfaces of minerals that have iron contents, such as olivine, pyroxene, and amphibole, as well as the rocks containing these minerals, such as basalt, gabbro, and peridotite. Rust is very stable at the Earth's surface. Indeed, anyone who owns an older car is well aware that rust does not dissolve and wash off in the local car wash.

Hydrolysis In hydrolysis, H^+ or OH^- ions from water molecules displace other ions from a mineral's structure. Aluminum-rich silicates such as the feldspars, the most abundant minerals in the Earth's crust, are weathered primarily by hydrolysis. In a typical hydrolysis reaction, the potassium ions in potassium feldspar ($KAlSi_3O_8$) are replaced with water's hydrogen ions, forming the stable clay mineral kaolinite ($Al_2Si_2O_5(OH)_4$). The clays formed during hydrolysis represent an important component of many soils and of oceanic mud.

New Words and Expressions

1.crevice ['krevis] *n.* (墙壁，岩石等的)裂缝
2.take root 生根，扎根
3.buckle ['bʌkl] *v.* 弯曲，褶皱
4.sidewalk ['saidwɔ:k] *n.* 人行道
5.boulevard ['bu:livɑ:d] *n.* <美>林荫大道
6.pebble ['pebl] *n.* 卵石，石子
7.ingest [in'dʒest] *vt.* 摄取，咽下
8.cumulative ['kju:mjulətiv] *a.* 累积的
9.abrasion [ə'breiʒən] *n.* 磨蚀(作用)
10.scrape [skreip] *vt.* 刮，擦
11.swirl [swə:l] *vt.* 使成旋涡
12.gusty ['gʌsti] *a.* 阵风的，起大风的
13.dissolution [disə'lju:ʃən] *n.* 溶解(作用)
14.oxidation [ɔksi'deiʃən] *n.* 氧化
15.hydrolysis [hai'drɔlisis] *n.* 水解(作用)
16.charged ion 带电离子
17.halite ['hælait] *n.* 岩盐
18.chloride ['klɔ:raid] *n.* 氯化物
19.gypsum ['dʒipsəm] *n.* 石膏
20.limestone ['laimstəun] *n.* 石灰岩
21.precipitate [pri'sipiteit] *vt.* 使沉淀(出)
22.hematite ['hemətait] *n.* 赤铁矿
23.goethite ['gəuθait] *n.* 针铁矿
24.yellowish ['jeləuiʃ] *a.* 微黄色的
25.limonite ['laimə,nait] *n.* 褐铁矿
26.rust [rʌst] *n.* 铁锈
27.stain [stein] *v.* 染污，玷污
28.kaolinite ['keiəlinait] *n.* 高岭石

阅读材料

岩石与风化

(二)其他机械风化过程

几乎所有的岩石都有一些裂纹和空洞。植物和树木可以在表部岩石中的裂隙生根。虽然岩石看起来坚硬，可以抵挡根的生长，但树根生长施加在裂隙上的力惊人的大，完

全能够扩大裂隙。一些有树木成排生长的人行道隆起和破坏令人信服地说明这种树根生长时的风化能力。

动物也有助于机械风化。例如，一些较大的动物可能在石头上或卵石上行走，将石头或卵石压碎成更小的颗粒。一些鸟类摄取石子，作为它们消化过程中的研磨工具，石子被磨小后，被鸟排出体外。即使很小的生物如蚯蚓和昆虫，它们积累的活动也能有助于将岩石破碎为更小的碎片。

当岩石或矿物在搬运过程中碰撞，或者当松散的被运输物质与静止岩石暴露面摩擦时，因磨蚀也会产生机械风化。例如，旋转水流或阵风搬运的沉积物碎片彼此碰撞研磨，或与其他岩石面碰撞研磨，使之破碎为更小的颗粒。类似地，冰川底部岩石在搬运中会和基岩发生摩擦，岩石会被研磨得更小。

(三)化学风化

化学风化主要通过水参与的反应改变矿物和岩石的组成。因为水将离子携带到反应发生的地方，并参与反应，然后将反应产物带走，因此水是控制化学风化速率唯一的最重要因素。岩石化学风化主要经过三个过程：溶解、氧化和水解。

溶解　在溶解作用中，矿物或岩石中的离子或离子组被水溶解运走。正如我们在相关章节中知道的，水分子可以通过吸引溶解矿物并从矿物表面把带电离子移开。例如，岩盐溶解发生时，带正离子的水分子吸引和移走氯离子(Cl^-)，带负离子的水分子吸引和移走钠离子(Na^+)。

一些矿物沉积物，如含有石膏和岩盐的沉积物，容易被水溶解。然而，在很多情况下，水自身不能从矿物或岩石中移走离子，而是与周围的其他化合物反应形成一种物质——通常是一种酸——这种酸在起作用。这类反应通常包括水与二氧化碳(CO_2)反应生成碳酸(H_2CO_3)。碳酸反过来与石灰岩反应，溶解石灰岩。世界上的洞穴大多数是通过这种过程形成的(见图 5.5)。

由水的作用从岩石或矿物中移动的离子再由水搬运离开叫溶解。当水最终蒸发，这些物质残留下来，被称为从溶液中沉淀出来。如我们在有关章节中所看到的，这种沉淀物质表示了一种重要的沉积形式，形成许多沉积岩。

氧化　在氧化作用中，矿物离子与氧离子结合。例如，当铁镁质岩石中的铁离子(Fe^{2+})与空气中的氧离子结合，它们形成铁氧化物 Fe_2O_3(赤铁矿)。其他的铁氧化物，如棕黄色的针铁矿和微黄色的褐铁矿，与水作用形成富铁的矿物和岩石。铁氧化物，通常被称为铁锈，可以污染含铁成分的矿物表面，如橄榄石、辉石、闪石以及含有这些矿物的岩石，如玄武岩、辉长岩和橄榄岩。铁锈在地球表面非常稳定。事实上，有旧汽车的人要清楚地意识到铁锈在当地的洗车处不能被溶解和洗刷掉。

水解　在水解作用中，水分子中的 H^+或 OH^-离子取代了矿物结构中的其他离子。富含铝的硅酸盐如地壳中含量最丰富的矿物——长石，主要通过水解作用被风化。在典型的水解反应中，钾长石($KAlSi_3O_8$)中的钾离子被水中的氢离子取代，形成稳定的黏土矿物高岭石($Al_2Si_2O_5(OH)_4$)。在水解过程中形成的黏土代表了多种土与海洋淤泥的重要成分。

Unit 6

Text

Causes of Earthquakes

What causes earthquakes? An earthquake is a trembling or shaking of the ground caused by the sudden release of energy stored in the rocks beneath Earth's surface. As described in article, great forces acting deep in the Earth may put a stress on the rock, which may bend or change in shape (strain). If you bend a stick of wood, your hands put a stress (the force per unit area) on the stick; its bending (a change in shape) is the strain.

Like a bending stick, rock can deform only so far before it breaks. When a rock breaks, waves of energy are released and sent out through the Earth. These are seismic waves, the waves of energy produced by an earthquake. It is the seismic waves that cause the ground to tremble and shake during an earthquake.

The sudden release of energy when rock breaks may cause one huge mass of rock to slide past another mass of rock into a different relative position. As you know from previous part the break between the two rock masses is a fault. The classic explanation of why earthquakes take place is called the elastic rebound theory (Fig. 6.1). It involves the sudden release of progressively stored strain in rocks, causing movement along a fault. Deep-seated internal forces (tectonic forces) act on a mass of rock over many decades. Initially the rock bends, but does not break. More and more energy is stored in the rock as the bending becomes more severe. Eventually the energy stored in the rock exceeds the breaking strength of the rock, and the rock breaks suddenly, causing an earthquake. Two masses of rock move past one another along a fault. The movement may be vertical, horizontal, or both (Fig. 6.2). The strain on the rock is released; the energy is expended by moving the rock into new positions and by creating seismic waves.

Recently some modifications have been suggested for the sequence of events shown in Figure 6.1. The classic model implies that existing faults are strong; a very large stress must act to break rocks along a fault. The new idea is that faults are weak, and only need a small stress to cause rupture and an earthquake. The evidence for the new idea is suggestive, but not yet conclusive, so we currently have two models for fault behavior. The weak-fault model poses serious problems for earthquake prediction, as you will see with some documents.

The brittle behavior of breaking rock is characteristic only of rocks near Earth's surface. Rocks at depth are subject to increased temperature and pressure, which tend to reduce brittleness. Deep rocks deform plastically (ductile behavior) instead of breaking (brittle

behavior); hence, there is a limit to the depth where faults can occur.

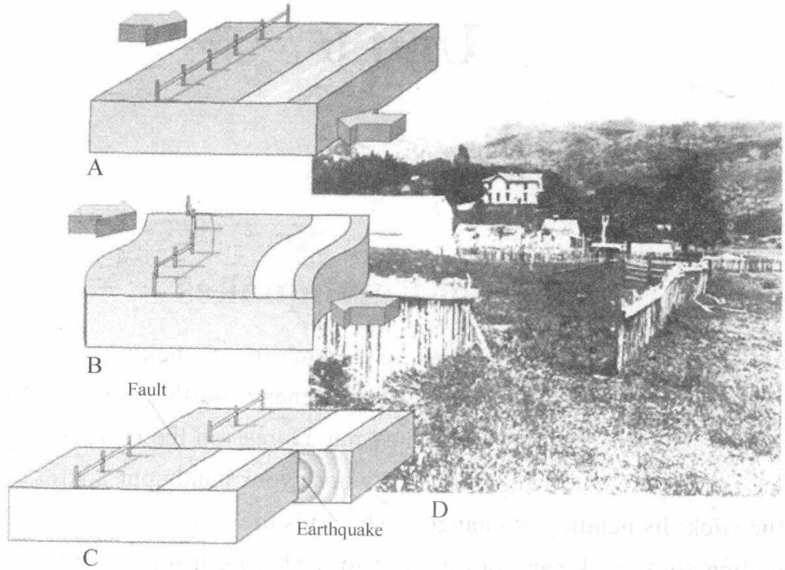


Figure 6.1 The elastic rebound theory of the cause of earthquakes
(A) Rock with stress acting on it. (B) Stress has caused strain in the rock. Strain builds up over a long period of time. (C) Rock breaks suddenly, releasing energy, with rock movement along a fault. Horizontal motion is shown; rocks can also move vertically or diagonally. (D) Fence offset nearly 3 meters after 1906 San Francisco earthquake. Photo by G. K. Gilbert, U.S. Geological Survey



Figure 6.2 Horizontal offset of rows in a lettuce field, 1979, El Centro, California
Photo by University of Colorado; courtesy National Geophysical Data Center, Boulder, Colorado

Most earthquake are associated with movement on fault, but in some quakes the connection with faulting may be difficult to establish. Four recent California quakes, including the 1994 Northridge quake, occurred on buried thrust faults, some of which were unknown and none of which involved surface displacement. Most earthquakes in the eastern United States are also not associated with surface displacement. Earthquakes also occur during explosive volcanic eruptions and as magma forcibly fills underground magma chambers prior to many eruptions; these quakes may not be associated with fault movement at all.

Another cause has been recently postulated for deep earthquakes (100 to 670 kilometers below the surface), essentially all of which are found on cold, subducting plates sliding down into the mantle. Although the downgoing plates are colder than the surrounding rock, the high temperature and pressure at depth suggests to some geologists that the rock in the plates should behave plastically rather than breaking in the brittle manner of near-surface rocks. The suggested cause of deep quakes is mineral transformations within the downgoing rock, as pressure collapses one mineral into a denser form. Lab experiments have shown bodies of the new, denser minerals along fractures. Whether the process occurs on a large scale to produce large quakes is unknown. Similar suggestions for the cause of deep quakes include the dehydration of water-containing serpentine and the conversion of serpentine into glass. Both these processes occur suddenly on small fractures in lab experiments.

New Words and Expressions

1.cause [kɔːz] *n.* 原因，起因
2.tremble ['trembl] *n.* 颤动
3.deform [diː'fɔːm] *v.* 使变形，畸变，畸形
4.seismic ['saizmik] *a.* 地震引起的，与地震有关的
5.seismic waves 地震波
6.slide [slaid] *v.* 滑动，山崩，地滑
7.classic ['klæsik] *a.* 第一流的，经典的
8.rebound [ri'baund] *n.* 回弹
9.elastic rebound theory 弹性回弹说
10.progressively [prə'gresivli] *adv.* 日益增多地
11.tectonic force 构造作用力
12.build up 增进，增大
13.motion ['məuʃən] *n.* 运动，动作
14.diagonally [dai'ægənli] *adv.* 对角地
15.offset ['ɔːfset] *vi.* 偏移
16.lettuce ['letis] *n.* 莴苣，生菜
17.rupture ['rʌptʃə(r)] *n.* 断裂
18.suggestive[sə'dʒestiv] *a.* 提示的，启发的，可作参考的
19.conclusive [kən'kluːsiv] *a.* 确实的，最后的，决定性的
20.pose [pəuz] *v.* 形成，引起
21.brittleness ['britlnis] *n.* 脆性，脆度
22.ductile ['dʌktail] *a.* 延性的，韧性的，黏性的
23.thrust fault 冲断层
24.displacement [dis'pleismənt] *n.* 位移
25.explosive [iks'pləusiv] *a.* 爆炸性的，爆发性的
26.eruption [i'rʌpʃən] *n.* 爆发，喷发
27.magma ['mægmə] *n.* 岩浆
28.forcibly['fɔːsəbəli] *adv.* 强制地
29.magma chamber 岩浆空间
30.postulate ['pɔstjuleit] *vt.* 假设，假定
31.subduct [sʌb'dʌkt] *vt.* 下转，向下压或向下拉
32.subducting plate 俯冲板块，消减板块
33.slide down 滑落
34.mantle ['mæntl] *n.* 地幔
35.dehydration [ˌdiːhai'dreiʃən] *n.* 脱水
36.serpentine ['səːpəntain] *n.* 蛇纹岩
37.conversion [kən'vəːʃən] *n.* 转化，转变

地震的成因

地震的成因是什么？地震是地表以下岩石储存的能量突然释放而引起的地面颤动或震动。就像在有关文章中所描述的那样，在地球深处巨大的作用力会对岩石施加压力，使岩石弯曲或改变形状(变形)。如果你弯曲一根木棍，你的手对棍子施加应力(单位面积力)；木棍的弯曲(形状的改变)就是变形。

就像弯曲的木棍，岩石在破裂前只发生变形。当岩石破裂时，释放能量波，从地球内向外传播。这些就是地震波，这种能量波是由地震产生的。在地震期间，地震波引起地面的颤动和震动。

岩石破裂时，能量的突然释放可以引起一块巨大的岩体沿另一块岩体滑动，使岩体处于不同的相对位置。如同你从前面的部分所知，两块岩体间的断裂称为断层。地震成因的权威解释被称为弹性回弹理论(见图 6.1)。该理论认为逐渐储存在岩石中的变形突然释放，导致岩石沿着断层运动。深处内部作用力(构造作用力)长时间作用于岩体。起初岩石只是弯曲，但没有破裂。但随着弯曲变得更加严重，越来越多的能量储存在岩石中。最终储存在岩石中的能量超过了岩石的破坏强度，岩石突然破裂，产生地震。两块岩体沿着断层做相对运动。这种运动可能是垂直的、水平的或兼而有之(见图 6.2)。这样，岩石中的变形被释放；能量受到消耗，把岩石移到新的位置且引起地震波。

近来有学者建议对图 6.1 所示事件发生的顺序作一些修改。经典的模型暗示存在的断层胶结牢固，必须有非常大的推力沿断层作用才能使岩石破裂。而新的观点认为断层胶结软弱，只需要很小的推力就会产生断裂和地震。新观点已提出证据，但还不是结论，因此目前我们有两种断层特性模型。你会在某些文献中看到，弱断层模型给地震的预测带来严重的困难。

破坏岩石的脆性只是近地表岩石的特征。地层深处的岩石受到逐渐增加的温度和压力作用，脆性降低。深成岩石发生塑性变形(黏性特征)而不是破坏(脆性特征)；因此，断层产生的深度有一定的界限。

多数地震与断层移动有关，但有些地震与断层的关系却很难确定。四个近期的加州地震，包括 1994 年的 Northridge 地震，都发生在深部的逆冲断层上，它们中有些是不为人知的，并且都没有发生表面位移。美国东部的大部分地震也与表面位移无关。在火山猛烈喷发和岩浆强有力地充填前期喷发所留下的地下岩浆空间时也会发生地震；但这些地震与断层运动没有丝毫关系。

最近深成地震(地表以下 100~670 km)的其他成因已经被假定，基本上所有的深成地震都发生在冷的俯冲板块上，且板块下滑到地幔。尽管俯冲板块比周围岩石冷，但深处的高温和高压告诉地质学家俯冲板块内的岩石应该表现为塑性，而不是像近地面岩石那样脆性破裂。深成地震成因推测深处岩石矿物会发生变化，受压力损坏的矿物成为密实的形式。实验室试验已表明沿着破裂会出现新的更致密的矿物体。然而在大范围内这一过程是否产生了大型地震还是未知的。对深成地震类似的建议还包括含水蛇纹岩脱水和蛇纹岩转化为玻璃质。这些过程都在实验室试验的岩石小断裂处突然发生。

Reading Material

Seismic Waves

The point within the Earth where seismic waves first originate is called the focus (or hypocenter) of the earthquakes (Fig. 6.3). This is the center of the earthquake, the point of initial breakage and movement on a fault. Rupture begins at the focus and then spreads rapidly along the fault plane. The point on the Earth's surface directly above the focus is the epicenter.

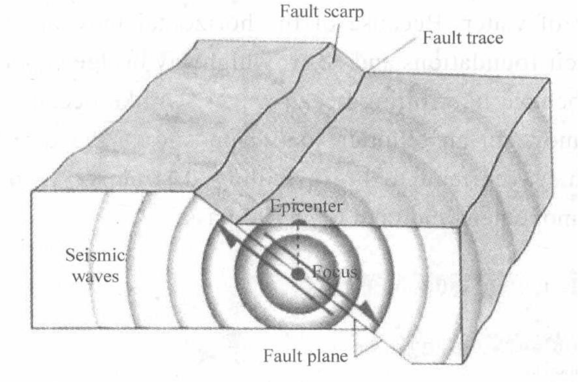


Figure 6.3 The focus of an earthquake is the point where rocks first break along a fault; seismic waves radiate from the focus

The epicenter is the point on the Earth's surface directly above the focus

Two types of seismic waves are generated during earthquakes. Body waves are seismic waves that travel through the Earth's interior, spreading outward from the focus in all directions. Surface waves are seismic waves that travel on Earth's surface away from the epicenter, like water waves spreading out from a pebble thrown into a pond. Rock movement associated with seismic surface waves dies out with depth into the Earth, just as water movement in ocean waves dies out with depth.

1 Body Waves

There are two types of body waves, both shown in Figure 6.4((A), (B)). A P wave is a compressional (or longitudinal) wave in which rock vibrates back and forth parallel to the direction of wave propagation. Because it is a very fast wave, traveling through near surface rocks at speeds of 4 to 7 kilometers per second, a P wave is the first (or primary) wave to arrive at a recording station following an earthquake.

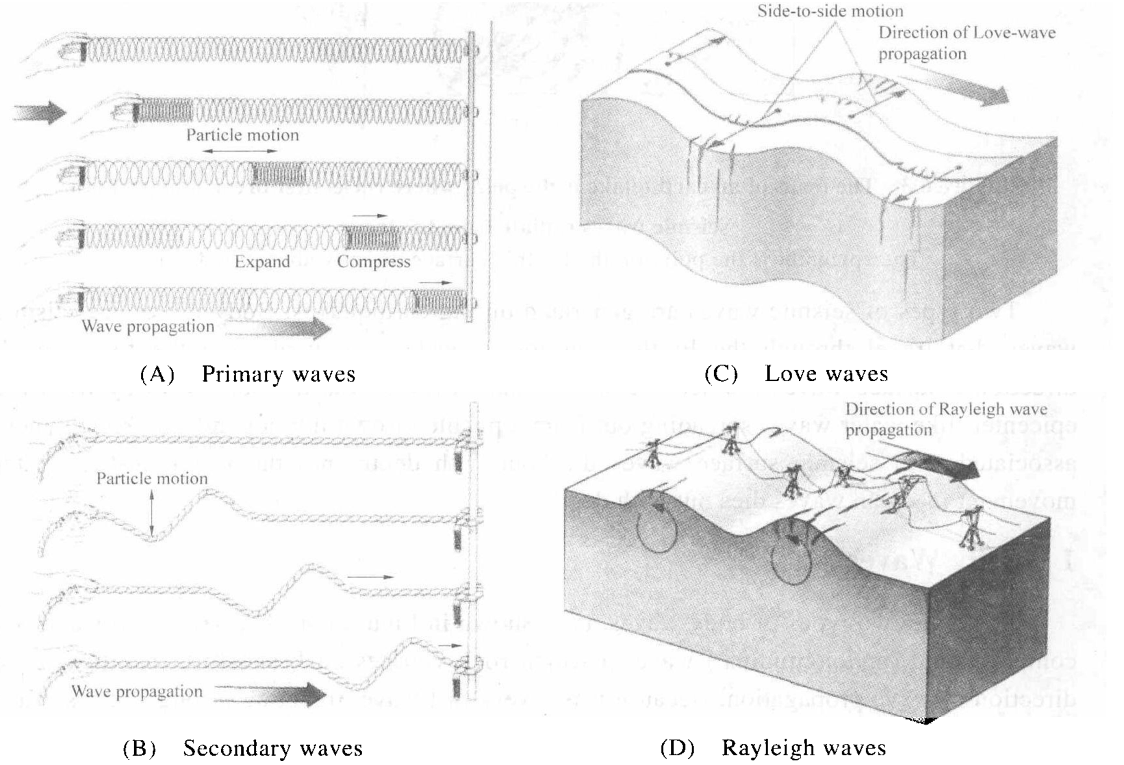
The second type of body wave is called an S wave (secondary) and is a slower, transverse wave that travels through near surface rocks at 2 to 5 kilometers per second. An S wave is propagated by a shearing motion much like that in a stretched, shaken rope. The rock vibrates perpendicular to the direction of wave propagation, that is, crosswise to the direction the waves are moving. Both P waves and S waves pass easily through solid rock. A P wave can also pass through a fluid (gas or liquid), but an S wave cannot.

2 Surface Waves

Surface waves are the slowest waves set off by earthquakes. In general, surface waves cause more property damage than body waves because surface waves produce more ground movement and travel more slowly, so they take longer to pass. The two most important types of surface waves are Love waves and Rayleigh waves, named after the geophysicists who discovered them.

Love waves are most like S waves that have no vertical displacement. The ground moves side to side in a horizontal plane that is perpendicular to the direction the wave is traveling or propagating (Fig.6.4(C)). Like S waves, Love waves do not travel through liquids and would not be felt on a body of water. Because of the horizontal movement, Love waves tend to knock buildings off their foundations and destroy highway bridge supports.

Rayleigh waves behave like rolling ocean waves. Unlike ocean waves, Rayleigh waves cause the ground to move in an elliptical path opposite to the direction the wave passes (Fig.6.4(D)). Rayleigh waves tend to be incredibly destructive to buildings because they produce more ground movement and take longer to pass.



(A) Primary waves (C) Love waves

(B) Secondary waves (D) Rayleigh waves

Figure 6.4 Particle motion in seismic waves

(A) A P wave is illustrated by a sudden push on the end of a stretched spring or Slinky. The particles vibrate parallel to the direction of wave propagation. (B) An S wave is illustrated by shaking a loop along a stretched rope. The particles vibrate perpendicular to the direction of wave propagation. (C) Love waves behave like S waves in that the particle motion is perpendicular to the direction of wave travel along the earth's surface. (D)Rayleigh waves are like ocean waves and cause a rolling motion on the earth's surface. The particle motion is elliptical and opposite (counterclockwise) to the direction of wave propagation

New Words and Expressions

1.hypocenter ['haipəusentə(r)] *n.* 震源
2.breakage ['breikidʒ] *n.* 破坏，破损
3.epicenter ['episentə(r)] *n.* 震中
4.body wave 体波
5.surface wave 面波
6.pebble ['pebl] *n.* 卵石
7.die out 逐渐消失
8.ocean wave 海浪
9.compressional [kəm'preʃ(ə)nəl] *a.* 压缩性的，与压缩有关的
10.longitudinal [lɔndʒi'tju:dinl] *a.* 纵向的
11.vibrate [vai'breit] *v.* 振动,振荡
12.propagation [ˌprɔpə'geiʃən] *n.* 传播
13.transverse ['trænzvə:s] *a.* 横向的
14.propagate ['prɔpəgeit] *v.* 传播
15.stretch [stretʃ] *v.*伸展，伸长
16.crosswise ['krɔswaiz; (*US*) 'krɔ:s-] *a.* 交叉的，横的
17.elliptical [i'liptikəl] *a.* 椭圆的
18.incredibly [in'kredibili] *adv.* 不可思议地

阅读材料

地 震 波

在地球内最先产生地震波的点称为地震震源(震源)(见图 6.3)。这是地震的中心，断裂的破坏和移动从这里开始。断裂从震源开始，然后沿着断层面迅速扩展。地面上位于震源正上方的点称为震中。

在地震中产生两种类型的地震波。体波是穿过地球内部，从震源向外沿各方向传播的地震波。面波是在地球表面上从震中向外传播的地震波，如同扔进池塘的卵石产生的水波向外传播一样。与地震表面波有关的岩石运动会随着地球深度的增加逐渐消失，就像海浪中的水体运动会随着海水深度的增加而逐渐停止。

一、体波

如图 6.4(A)、(B)所示，有两种体波类型。P 波是一种压缩性波(纵波)，在纵波中，岩石沿平行于波的传播方向往复震动。波传播得很快，近地表为 4~7 km/s，地震发生时，P 波是最先到达记录站的。

体波的第二种类型被称为 S 波，传播较慢，为横波，近地表 2~5 km/s。S 波类似于一个拉伸、抖动的绳子所作的剪切运动向外传播。岩石震动的方向与波传播方向垂直，即与波运动的方向垂直。P 波和 S 波都很容易通过固体岩石。P 波也能通过流体(气体或液体)，但 S 波不能。

二、面波

面波是地震产生的速度最慢的波。通常与体波相比，面波会造成更大的财产损失，这是因为面波导致了更大的地面运动，并且传播慢，花费时间长。面波最重要的两种类型是 Love 波和 Rayleigh 波，这两种波是以发现它们的地球物理学家命名的。

Love 波没有垂直位移，非常像 S 波。地面在与波运动或传播方向正交的水平面内来回运动(见图 6.4(C))。如同 S 波，Love 波在液体中不传播，对水体毫无影响。由于它是水平运动，Love 波容易毁坏建筑物地基和高速公路桥墩。

Rayleigh 波类似于翻滚的海浪。但不同于海浪，Rayleigh 波能引起地面沿着与波传播方向相反的方向做椭圆运动(见图 6.4(D))。由于 Rayleigh 波会产生更多的地面运动并且通过的时间长，所以它会令人难以置信地破坏建筑物。

Unit 7

Text

Soil Mechanics

Soil mechanics is concerned with the use of the laws of mechanics and hydraulics in engineering problems related to soils. Soil is natural aggregate of mineral grains, with or without organic constituents, formed by the chemical and mechanical weathering of rock. It consists of three phases: solid mineral matter, water, and air or other gas. Soil are extremely variable in composition, and it was this heterogeneity that long discouraged scientific studies of these deposits. Gradually, the investigation of failures of retaining walls, foundations, embankments, pavements, and other structures resulted in a body of knowledge concerning the nature of soils and their behaviour sufficient to give rise to soil mechanics as a branch of engineering science.

1 History

Little progress was made in dealing with soil problems on a scientific basis until the latter half of the 18th century, when the French physicist Charles-Augustin de Coulomb published his theory of earth pressure (1773). In 1857 the Scottish engineer William Rankine developed a theory of equilibrium of earth masses and applied it to some elementary problems of foundation engineering. These two classical theories still form the basis of current methods of estimating earth pressure, even though they were based on the misconception that all soils lack cohesion, as does dry sand. Twentieth-century advances have been in the direction of taking cohesion into account; understanding the basic physical properties of soils in general and of the plasticity of clay in particular; and systematically studying the shearing characteristics of soils—that is, their performance under conditions of sliding.

Both Coulomb's and Rankine's theories assumed that the surface of rupture of soil subjected to a shearing force is a plane. While this is a reasonable approximation for sand, cohesive soils tend to slip along a curved surface. In the early 20th century, Swedish engineers proposed a circular arc as the surface of slip. During the last half century considerable progress has been made in the scientific study of soils and in the application of theory and experimental data to engineering design.

A significant advance was made by the German engineer Karl Terzaghi, who in 1925 published a mathematical investigation of the rate of consolidation of clays under applied pressures. His analysis, which was confirmed experimentally, explained the time lag of

settlements on fully waterlogged clay deposits. Terzaghi coined the term soil mechanics in 1925 when he published the book "Earth—Building Mechanics" .

Research on subgrade materials, the natural foundation under pavements,was begun about 1920 by the U.S. Bureau of Public Roads. Several simple tests were correlated with the properties of natural soils in relation to pavement design. In England ,the Road Research Board was set up in 1933. In 1936 the first international conference on soils was held at Harvard University.

Today, the civil engineer relies heavily on the numerical results of tests to reinforce experience and correlate new problems with established solutions. Obtaining truly representative samples of soils for such tests, however, is extremely difficult; hence there is a trend toward testing on the site instead of in the laboratory, and many important properties are now evaluated in this way.

2 Engineering Properties of Soils

The properties of soils that determine their suitability for engineering use include internal friction, cohesion, compressibility, elasticity, permeability, and capillarity.

Internal friction is the resistance to sliding offered by the soil mass. Sand and gravel have higher internal friction than clays; in the latter an increase in moisture lowers the internal friction. The tendency of a soil to slide under the weight of a structure may be translated into shear; that is, a movement of a mass of soil in a plane, either horizontal, vertical, or other. Such a shearing movement involves a danger of building failure.

Also resisting the danger of shear is the property of cohesion, which is the mutual attraction of soil particles due to molecular forces and the existence of moisture between them. Cohesion forces are markedly affected by the amount of moisture present. Cohesion is generally very high in clays but almost nonexistent in sands or silts. Cohesion values range from zero for dry sand to 100 kPa for very stiff clays.

Compressibility is an important soil characteristic because of the possibility of compacting the soil by rolling, tamping, vibration, or other means, thus increasing its density and load-bearing strength.

An elastic soil tends to resume its original condition after compaction. Elastic(expansible) soil are unsuitable as subgrades for flexible pavements since they compact and expand as a vehicle passes over them, causing failure of the pavement.

Permeability is the property of a soil that permits the flow of water through it. Freezing-thawing cycles in winter and wetting-drying cycles in summer alter the packing density of soil grains. Permeability can be reduced by compaction.

Capillarity causes water to rise through the soil above the normal horizontal plane of free water. In most soils numerous channels for capillary action exist; in clays, moisture may be raised as much as 30 feet by capillarity.

Density can be determined by weight and volume measurements or by special measuring devices. Stability of soils is measured by an instrument called a stabilometer, which specifically measures the horizontal pressure transmitted by a vertical load. Consolidation is the compaction or pressing together of soil that occurs under a specific load condition; this property is also tested.

3 Site Investigation

Soil surveys are conducted to gather data on the nature and extent of the soil expected to be encountered on a project. The amount of effort spent on site investigation depends on the size and importance of the project; it may range from visual inspection to elaboration subsurface exploration by boring and laboratory testing. Collection of representative samples is essential for proper identification and classification of soil. The number of samples taken depends on previously available data, variation in soil types, and the size of the project. Generally, in the natural profile at a location, there is more variation in soil characteristics with depth than with horizontal distance. It is not good practice to collect composite samples for any given horizon(layer), since this does not truly represent any one location and could prove misleading. Even slight variations in soil characteristics in a horizon should be duly noted. Classification of the soil in terms of grain size and the liquid and plastic limits are particularly important steps.

An understanding of the eventual use of the data obtained during site investigation is important. Advance information on site conditions is helpful in planning any survey program. Information on topography, geological features(outcrops, road and stream cuts, lake beds, weathered remnants, etc.), paleontological maps, aerial photographs, well logs, and excavations can prove invaluable. Geophysical exploration methods yield useful corroboratory data. Measurement of the electrical resistivity of soils provides an insight into several soil characteristics. Seismic techniques often are used to determine the characteristics of various subsurface strata by measuring the velocity of propagation of explosively generated shock waves through the strata. The propagation velocity varies widely for different types of soils. Shock waves also are utilized to determine the depth of bedrock by measuring the time required for the shock wave to travel to the bedrock and return to the surface as a reflected wave.

Dependable subsurface information can only be obtained by excavation. A probe rod pushed into the ground indicates the penetration resistance. Water jets or augers are used to bring subsurface materials to the surface for examination. Colour change is one of the significant elements such an examination can reveal. Various drilling methods are employed to obtain chips from depth. Trenches or pits provide more complete information for shallow depths. Pneumatic or diamond drilling may be required if hard rock is encountered. At last a few of the boreholes should exceed the depth of significant stress that is established for the

structure.

Avoidance of structural disturbance of the sample is not critical for some tests but is very important for in-place density or shearing strength measurements.

Complete and accurate records, such as borehole logs, must be prepared and maintained, and the sample themselves must be retained for future inspection.

New Words and Expressions

1.aggregate ['ægrigeit] *n.* 集合体
2.heterogeneity [ˌhetərəudʒi'niːiti] *n.* 不均匀
3.lag [læg] *n.* 迟延
4.waterlogged ['wɔːtəlɔgd] *a.* 饱水的
5.tamp ['tæmp] *vt.* 夯实
6.density ['densiti] *n.* 密度
7.resume [ri'zjuːm] *vt.* 再恢复
8.flexible ['fleksəbl] *a.* 柔软的，有弹性的
9.thaw [θɔː] *v.* 融化
10.capillarity [kæpi'læriti] *n.*毛细管作用
11.stabilometer [ˌsteibi'lɔmitə] *n.* 稳定仪
12.elaborate [i'læbərət] *a.* 详尽的
13.composite ['kɔmpəzit, -zait] *n.* 合成物
14.duly ['djuːli] *adv.* 适当地
15.outcrop ['autkrɔp] *n.* 露头
16.paleontological [ˌpæliɔn'tɔlədʒikəl] *a.* 古生物学的
17.corroboratory [kə'rɔbərətəri] *a.* 证实的
18.insight ['insait] *n.* 洞悉，理解
19.probe [prəub] *n.* 探测
20.auger ['ɔgə] *n.* 麻花钻，土钻，钻孔机
21.chip [tʃip] *n.* 碎屑物
22.pneumatic [nju(ː)'mætik] *a.* 气动的
23.significant [sig'nifikənt] *a.* 值得注意的
24.disturbance [dis'təːbəns] *n.* 断裂，损伤

土 力 学

土力学是一门在工程上与土有关的科学，它使用了力学和水力学的定律。土是含或不含有机质的矿物颗粒自然的堆积，是由岩石受到化学和力学机械风化而成。它由三种成分构成：固体矿物、水和空气或其他气体。土在成分上有很大变化，它很复杂，使其长时间对这种材料的研究受到阻碍。由于对残墙、基础、堤坝、道路和其他建筑物破坏的不断调查产生了与土自然状态和它的特性有关知识的集合体，且演义为土力学作为工程科学的分支。

一、历史

直到 18 世纪后半叶以科学为依据的土力学有关的问题才得到一些进展，这时法国物理学家 Charles-Augustin de Coulomb 发表了他的土压力理论(1773)。在 1857 年苏格兰工程师 Willlian Rankine 提出了土体平衡理论并用于基础工程的一些基本问题。尽管这两个理论有着错误，即所有土缺少黏结力类似干砂，但它们依然构成了估算土压力常用方法。20 世纪的进步是在计算中考虑了黏结力；知道了土总的基本物理特性和在特定条件下的塑性；系统研究了土的剪切特性，即在滑动条件下的表现。

Coulomb 和 Rankine 理论假定土受到剪切破坏面是一个平面。这对砂土基本可行，黏土滑动沿着曲面。在 20 世纪早期，瑞典工程师提出滑动面是一个圆弧。在最近半个世

纪为了工程设计在土的科学研究、理论应用和实验资料方面取得不少进步。

一个重要成就就是由德国工程师 Karl Terzaghi 得到的，他在 1925 年发表了在加压条件下，黏土固结速率的数学分析。他的分析由实验证实并解释了饱水黏土沉陷时间滞后效应。他于 1925 年出版了《土—建筑力学》一书并提出土力学这一术语。

在路基材料研究方面，道路下的天然地基大约是在 1920 年由美国垦务局开始研究的。有几种试件实验涉及到路基设计天然土的性质。在英国，道路研究委员会于 1933 年成立。1936 年关于土的第一次国际会议在哈佛大学举行。

今天，土木工程师多依赖于试验成果增加经验并把新问题与建立的解联系起来。对试验来说获得有代表性的土样是非常困难的；由此趋于现场试验替代室内试验，许多重要特性以这一方式评价。

二、土的工程性质

对土的性质来说，决定用于工程使用的指标包括摩擦系数、黏结力、压缩性、弹性、渗透性和毛细现象。

摩擦系数是土体滑动所产生的抗滑现象。砂和砾石比黏土摩擦系数要大；在黏土中增加水分会降低摩擦系数。在建筑物自重作用下土的滑动趋势以剪切的方式发生；也就是说，土体在平面上移动要么水平，要么垂直或其他方式。这样的剪切移动对建筑物是危险的。

抗剪切破坏也是土的黏结力的特性，它是土颗粒相互吸引产生的，与土颗粒之间的分子力和水分存在有关。黏结力明显受到水分的含量影响。黏结力在黏土中非常高，在砂和粉砂中几乎不存在。对于干砂来说，黏结力是零，对非常硬的黏土达到 100 kPa。

压缩性是土的一个重要特性，由于滚动、夯实、震动或其他手段可以使土发生密实，由此可增加它的密实度和承载能力。

任何有弹性的土在压实后会趋于恢复到原有状态。弹性土(膨胀土)作为柔性道路路基是不合适的，因为当车辆经过时会产生压实和膨胀，这样引起道路破坏。

渗透性是允许水通过土渗流的一种性质。在冬天的冻融循环、夏天的湿干循环会改变土颗粒的密度。压实会使渗透性减小。

毛细作用使水升高，即高出土中垂直自由水位所形成的水平面以上。对大部分土来说有大量毛细作用通道存在。在黏土中由于毛细作用，水可以升高 30 英尺。

密度是重量与实测土的体积之比或用专用测量装置来确定。土的稳定性由稳定仪来测定，它可测定由垂直荷载引起的水平力。固结是一种密实或在特定荷载条件下使土压缩在一起。这种性质要进行试验。

三、现场调查

土的测绘是指在工程中对可能遇到的一定范围的土和其天然状态进行资料收集。现场调查所花费的工作量依赖于工程规模和重要性；可以由肉眼鉴定到用钻孔对地下钻探以及实验室试验。为了对土做适当鉴别和分类，收集有代表性试样是基本的。所取试件的数量依赖于以前所获得的资料、土的类型和工程的规模。一般在天然露头上，土的特

性在垂直方向比水平方向明显。在给定的水平方向(水平层)收集综合性试件是不合适的，因为这不能代表任何部位，而且会产生错误导向。甚至是土特性在水平方向轻微的变化都应给予记录。按土颗粒大小、液限和塑限做土的分类特别重要。

理解在现场调查期间所获得的资料的最终应用是重要的。在现场条件下所得到的信息对计划任何测绘内容是有帮助的。地形、地貌(露头、道路、溪水冲刷、湖床、风化残积物等)、古生物圈地图、航空照片、钻井日记和开挖提供了有价值的资料。地球物理方法可对一些资料进行验证。土的电阻率量测可提供了解一些土的特性。地震技术常用来确定不同地层的特征，通过爆炸使地震波穿过地层测其传播速度来实现。传播速度在不同类型的土中有着较大变化。地震波也可用于确定岩层的深度，方法是通过测量地震波到达岩层再反射到地表(反射波)所需要的时间获取岩层的埋深。

地下可信的信息只有开挖才可得到。插入地层中的钻头测杆可给出穿过地层的电阻。水枪和麻花钻可用于把地下资料带到地表进行检查。检查中所显示的颜色变化是值得注意的环节之一。为了获得深部的碎片可采用不同的钻探方法。在浅处可用沟槽或试坑来获得信息。如果达到坚硬岩石可用气动或金刚石钻进。为了修筑建筑物要打几个钻孔使其深度穿过显著应力区。

对有些试验来说，防止试件破坏是不重要的，但对测试原位密度和剪切强度非常关键。

完整和精确的记录如钻孔日记要准备好和保留好，试件本身也是如此，以备进一步检查。

Reading Material

Geologic Origins of Soils

It is a feature of earth's geologic activity that the rocks forming the earth's mantle are continually being pushed out of the earth onto the surface, where they are then exposed to earthquakes, glaciation, freeze-thaw, water erosion, chemical attack, waterborne abrasion, wind erosion, and other forms of weathering. Under such attack, the rocks are broken progressively into huge boulders, these into smaller boulders, these into cobbles, these into pebbles, and finally, the pebbles are reduced to grains. Deposits of these assorted particles of rock and rock grains are called soils.

There is at present no word in engineering geology that is used specifically to describe the ever-continuing reduction of rock into smaller and smaller particles. For the sake of simplicity, it is termed degradation in subsequent discussions. Degradation of rock into soil grains is not something that happened only in some vague geologic past. It is a continuing process, as active today as it was a million years ago.

As the size of the particles become progressively smaller, the particles become progressively easier to transport. Transported first by such things as glaciation and avalanche,

the particles are reduced to smaller and smaller size as they are subjected successively to rushing floods, then ,when smaller, by white water rapids, later by rapidly moving streams, eventually by muddy meandering rivers, and finally, when small enough, to wind and duststorms. At any stage, the particles might be deposited in a recognizable stratum for a few thousand years before something happens to cause them to be picked up, transported, and deposited in some new location along with particles transported similarly from a hundred other locations.

At every stage of deposition and stratification, water is the ever-present medium of erosion and transport. Water deep within the ground carries acids and bases that chemically attack the particles even when they are buried thousands of feet deep. At the surface, rain, snow, and sleet combine to erode, freeze-thaw, and further reduce chunks of rock into smaller and smaller pieces.

Whenever exposed, the soil particles become subject to organic attack by vegetation, carbon dioxide, and atmospheric acids, changing them chemically into other compounds or even other minerals. Picked up again, redeposited, and exposed again and again, the particles might undergo thousands of years of changes before they come to rest for a few hundred years in relative quiet. It is at one of these quiet periods that the foundation engineer is given a stratum of these particles on which to place a foundation.

Because nature works on such a huge scale, the strata are usually(but not always)so large that the foundation can be located entirely on one stratum. But underlying this stratum could be another stratum having vastly different engineering properties, and underlying this, yet another. The material to be used to support a building foundation is thus a heterogeneous mixture of minerals coming from countless sources over the breadth of a continent, randomly deposited, irregularly stratified, and absolutely inconsistent. It is, in short, soil.

With such a description, defining the engineering properties of a material as variable as soil would seem to be hopeless. Within recent years, however, real progress has been made in defining the engineering properties of soils. Although these properties are more appropriate within large brackets rather than to refined exact details, the response of most soils to a bearing load can now be predicted with some degree of confidence.

Insofar as the engineering properties of a soil are concerned, the mechanism of geologic transport, deposition, burial, and exposure is one of the more important influences. With few exceptions, all soils have been transported to their present locations from somewhere else. They have been blended, disturbed, chemically modified, reblended, mixed, crushed, restratified, picked up and redeposited, sometimes loaded by thousands of feet of overburden, and finally exposed when the overburden was eroded away. The mechanism by which the stratum was finally deposited and later exposed will be seen to be of profound importance when the soil is used as a foundation material.

A second major influence is the groundwater. The location of the water table, the amount

of its rise and fall throughout the year, and the chemistry of the groundwater can profoundly affect both the type of foundation and the ability of the soil to carry the foundation. In some circumstances, however, the water entering the soil from the surface can be far more important than that in the water table below.

A third major influence is the residue of vegetation. Even in the most barren deposits of soil, a few plants will manage to survive. The residue from their eventual death and decay will provide a somewhat more hospitable environment for the next generation of plants. The detritus of these plants in turn will deepen the fragile layer of organic material, providing a yet more fertile ground for other plants, and so on. Eventually, a gradient of organic material is developed, with the high organic content at the surface diminishing steadily with depth. As always, water is the primary vehicle for transporting the organic material downward. Aided in this case by disturbances from root penetration.

These combined effects of deposition, water percolation, vegetation, and other influences on the soil eventually produce a typical distribution of soil and organic matter called a soil profile by agronomists.

The presence of humus or organic material in a soil can cause serious changes in engineering properties as the organic material continues to decay. Due to this variability, engineered foundations must be placed well below the organic agricultural soils and into the parent soils of the Chorizon. The engineering properties of the soils in the Chorizon are reasonably constant and are not subject to change due to the decay of organic material.

Although soils have long been classified into broad groupings, the engineering properties of various classifications of soils cannot be determined once and used thereafter as constants; a soil in Wyoming classified as clay might have vastly different properties from a soil in Georgia classified as clay. There are, however, certain characteristics that are common to all soils regardless of origin or chemistry. Such characteristics can be used as a basis for soil classifications. One such characteristic is the size and shape of the individual particles that comprise the soil .

New Words and Expressions

1.mantle ['mæntl] *n.* 覆盖层，地幔
2.push out 推出
3.waterborne ['wɔːtəbɔːn] *a.* 水生(成、运)的
4.abrasion [ə'breiʒən] *n.* 磨损
5.boulder ['bəuldə] *n.* 巨砾
6.cobble ['kɔbl] *n.* 大鹅卵石
7.pebble ['pebl] *n.* 卵石
8.assorted [ə'sɔːtid] *a.* 各式各样的
9.degradation [ˌdegrə'deiʃən] *n.* 破坏，裂解
10.avalanche ['ævəˌlɑːnʃ] *n.* 雪崩
11.along with 同时
12.meander [mi'ændə] *v.* 蜿蜒而流
13.stratification [ˌstrætifi'keiʃən] *n.* 地层
14.ever-present ['evəˌprezənt] *a.* 总是存在的
15.base [beis] *n.* 碱
16.sleet [sliːt] *n.* 雨夹雪
17.chunk [tʃʌŋk] *n.* 厚块
18.pick up 选取

19.heterogeneous [ˌhetərəuˈdʒiːniəs] *a.* 不同种类的
20.inconsistent [ˌinkənˈsistənt] *a.* 不协调的
21.bracket [ˈbrækit] *n.* 分类
22.insofar as 据，就……(来说)
23.blend [blend] *vt.* 混合
24.profound [prəˈfaund] *a.* 极度的
25.barren [ˈbærən] *a.* 贫瘠的
26.manage [ˈmænidʒ] *v.* 经营
27.survive [səˈvaiv] *v.* 幸存，生还
28.hospitable [ˈhɔspitəbl] *a.* 有利的
29.fragile [ˈfrædʒail] *a.* 损坏的
30.detritus [diˈtraitəs] *n.* 碎屑
31.profile [ˈprəufail] *n.* 轮廓，剖面
32.agronomist [əˈgrɔnəmist] *n.* 农学家
33.broad [brɔːd] *a.* 概括的
34.humus [ˈhjuːməs] *n.* 腐殖质
35.regardless of 不管，不顾

阅读材料

土的地质起源

形成地幔的岩石在不断地冲出地壳到达地表，这是地球地质活动的一个特征，在地表它们会受到地震、冰川、冻融、水侵蚀、化学反应、水的磨损、风蚀作用，同时也受到其他形式的风化。在此情况下，岩石会逐渐地被破坏成为巨大的砾石，再变为较小的砾石，到大鹅卵石，到卵石，最后卵石成为砂砾。各种岩石颗粒和岩石颗粒沉积物叫做土。

目前，在工程地质中还没有专用名词来描述岩石不断变小一直成为微粒这一过程。从简明扼要考虑，在后面的讨论中用裂解一词。成为土粒的岩石裂解并不是在遥远的地质史上发生的。它是一个连续过程，在亿万年前和今天是一样的。

当颗粒变得越来越小，搬运会更容易。首先它们受到冰川和雪崩搬运，当它们不断地受到洪水冲刷时，颗粒会进一步减小，其后受到急流再后是急速小溪的作用，颗粒会更小，再后来是带泥质缓慢河水作用，最后变得足够小，受到风干，甚至成为沙尘暴。由于某种原因引起颗粒发生分选、搬运和在一些新位置沉积发生前，在任何一个阶段从可识别的地层知道这些微小颗粒已沉积了千万年，在其他地方颗粒搬运是类似的。

在沉积物和岩层每一时期，水总是在剥蚀和搬运中起作用。水携带着酸和碱渗入地下，颗粒会受到化学作用，甚至它们被埋藏几千英尺也会发生。在地表，雨、雪或雨夹雪联合发生剥蚀、冻融，这样会使岩石块度减小，成为越来越小的碎屑。

只要剥蚀存在，在植被、碳氧化合物、大气中酸的作用下土颗粒就会承受有机质腐蚀，使它们在化学上成为一种另外的化合物，甚至变为另外的矿物。在它们相对静止下来千百年之前，由于再分选，再沉积，一次又一次地剥蚀，使颗粒受到上千年的变化。在其中的一个静止期，基础工程师把土颗粒构成的土层作为基础。

由于自然界在一个巨大尺度上起着作用，岩层分布非常广，使地基完全布置在同一个岩层上(也有个别例外)。但这一层下面的一层会是有不同工程特性的另外一层，在其下的又是另外一层。而用于支撑建筑物基础的材料是不同种类矿物混合物，其来源于一个宽广大陆的无数地方，随机沉积，不规则和完全不协调的特征。人们叫它土。

如上所述，定义土这种易变材料的工程特性似乎有着困难。然而，最近几年，在确

定土的工程性质上取得了实质的进展。虽然这些性质更多表现在大的范围内而不是确切的细节，但大部分承载力效应在一定程度上是可预测的。

从土的工程特性而言，地质搬运机制、沉积、埋藏和剥露最为重要。除个别情况，所有土都是从其他的位置被搬运到现在的地方。它们被混合、扰动、化学变化，再混合、掺和、冲刷、成层作用、分选，再沉积，有时会受到上覆几千英尺荷载，最终，当上覆层受到剥蚀暴露于地表。当土作为地基材料时，土层最终沉积机制和其后裸露机制是最为重要的。

第二个主要影响因素是地下水。水位高程，在一年中水位升降的数量，地下水的化学作用对基础的类型、地基土的承载能力有着重要的影响。在一些情况下，从地表进入土中的水远比下面的地下水更为重要。

第三个主要影响是植物的残留物。即使在大部分贫瘠的土层中，也有少量的植物残存。植物最终死亡和腐烂的残积物在某些程度上为下一代植物提供了更加有利的环境，进而这些植物的碎屑转化成有机质的碎屑层，对其他植物提供了一个更为肥沃的土层。最终有机质成分增加了，与此同时，地表有着很高的有机含量的土随着深度增加有机质逐渐消失。水总是把有机质向下搬运的载体。根系的作用使这一过程得到加强。

土层，水的渗入，植物和其他因素联合作用最终构成土和有机物的分布，农学家称其为土剖面。

当有机质不断腐烂时，土中的腐殖质或有机质会使土的工程特性发生变化。由于这种变化，工程基础必须布置在有机农业土以下，放在 C 层(Chorizon，母质层)原生土中。C 层土的工程特性相当稳定，不会受到有机质腐烂的影响。

虽然土长时间以来已划分若干类，土各类的工程性质不能一次来确定，并认为是不变的；黏土 Wyoming 分类与 BGeorgia 分类在特性方面可能有着很大不同。然而，对整个土来说除了起源和化学成分外肯定会有共性。如此一些特性可作为土分类的一个依据。如土颗粒的大小和形状就是各类土所具有的。

Unit 8

Text

Darcy's Experimental Law and Field Extensions

Henry Darcy was a civil engineer concerned with the public water supply of Dijon, France, in particular the acquisition of data that would improve the design of filter sands for water purification. In search of this information, Darcy set out "to determine the laws of flow of water through sand." His method was experimental, the results of which were published in 1856.

The experimental apparatus employed by Darcy is shown in Figure 8.1. In these experiments, water was passed through the sand column and the volumetric flow rate Q was measured at the outlet. The cross-sectional area of the sand column was known, as was the length of the sand in the column. During the experiment, Darcy measured the distance between the water levels in the two manometers at various flow rates. The pertinent measurements included Q, a volumetric flow rate, L^3/T; A, the cross-sectional area, L^2; l, the length of sand column, L; and h_1-h_2, the difference in elevation of manometer readings, L. From these measurements, the pertinent calculations were Q/A, a velocity L/T; and $(h_1-h_2)/l$, a dimensionless quantity. The quantity Q/A is a volumetric flow rate per unit surface area and is termed specific discharge. The dimensionless quantity $(h_1-h_2)/l$ represents the change in water-level elevation in the manometer tubes over the distance through which the change takes place. This term is referred to as the gradient, or hydraulic gradient, and is often expressed with the calculus as $\partial h/\partial l$.

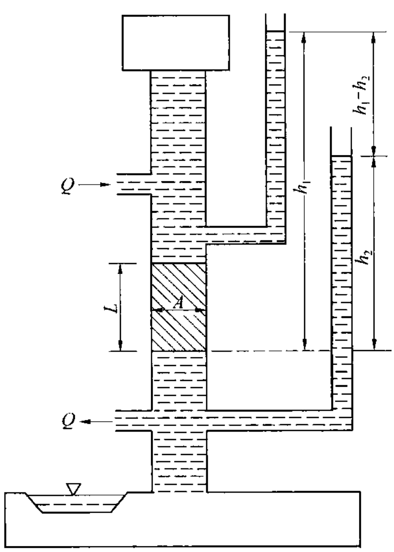


Figure 8.1 Darcy's laboratory apparatus

In the terms of the measurements and calculations just given, Darcy's law is expressed

$$\frac{Q}{A}=q=\frac{-K(h_1-h_2)}{l}=-K\frac{\partial h}{\partial l} \tag{8.1}$$

where, q is the volumetric flow rate per unit surface area, with units of velocity, and K is a constant of proportionality. Because the gradient is a dimensionless quantity, the

roportionality constant K has units of velocity. The minus sign is a convention that is employed because flow is in the direction of a decrease in water levels in the manometers, that is, from where h is high to where h is low(Fig.8.1). Darcy's equation may be stated in words as: the velocity of flow is proportional to the hydraulic gradient.

Darcy's law is valid for flow through most granular material. The law suggests a linear relationship between the specific discharge and the hydraulic gradient. This relationship holds as long as the flow is laminar. Under conditions of turbulent flow, the water particles take more circuitous paths. At the other extreme, for very-low-permeability materials, a minimum threshold gradient may be required before flow takes place.

Four aspects of Darcy's law require clarification from a field perspective: the specific discharge q, the water-level measurements, the gradient, and the proportionality constant K.

1 The Nature of Darcy's Velocity

As defined, the specific discharge q is a volumetric flow rate per unit surface area of sample. Because water only moves through the pore openings making up the surface area, Darcy's q is a "superficial" velocity. We thus define a more realistic velocity v that is a volumetric flow rate per unit area of connected pore space. The expression for v comes directly from Eq.8.1

$$\frac{Q}{n_e A} = \frac{q}{n_e} = v = -\left(\frac{K}{n_e}\right)\frac{\partial h}{\partial l} \tag{8.2}$$

where, $n_e A$ is the effective area of flow and n_e has been introduced as the effective porosity. Here, the quantity v is referred to as the linear or pore velocity of ground water. The linear velocity v will always be larger than the superficial velocity (specific discharge)and increases with decreasing effective porosity. Finally, it is convenient to designate the gradient $\partial h/\partial l$, as i so that Darcy's law may be expressed in the following forms

$$q=Ki \tag{8.3a}$$

$$Q=KiA \tag{8.3b}$$

$$v=Ki/n_e \tag{8.3c}$$

$$v=q/n_e \tag{8.3d}$$

The quantity q (as well as v) has both a magnitude and a direction, the later being toward decreasing elevation of water in the manometers.This makes q and v vector quantities.

2 Hydraulic Head: Hubbert's Force Potential

In Figure 8.1, the water-level elevations in the manometers are measured with reference to a common datum, taken arbitrarily at the base of the sample. Thus,the absolute value of the water-level elevations were of no concern to Darcy, only the differences between them. In this section, we are not interested in these differences but in what the actual water-level

measurements mean. For this purpose, it is convenient to introduce a counterpart of the laboratory manometer, known as a piezometer.

The piezometer is a tube or pipe used to measure water-level elevations in field situations. It is open at the top where measurements are taken and open at the bottom to facilitate the entrance of water. Such a device is shown in Figure 8.2, where the common datum is taken as sea level (zero elevation). As demonstrated by Hubbert(1940), the terms elevation, pressure, and total head on Figure 8.2 can be explained in terms of the conventional Bernoulli equation. This equation states that under conditions of steady flow, the total energy of an incompressible fluid is constant at all positions along a flow path in a closed system. This may be written as

$$gz+\frac{P}{\rho_w}+\frac{v^2}{2}=\text{constant} \tag{8.4}$$

where, g is the acceleration due to gravity, z is the elevation of the base of the piezometer, P is the pressure exerted by the water column, ρ_w is the fluid density, and v is velocity.

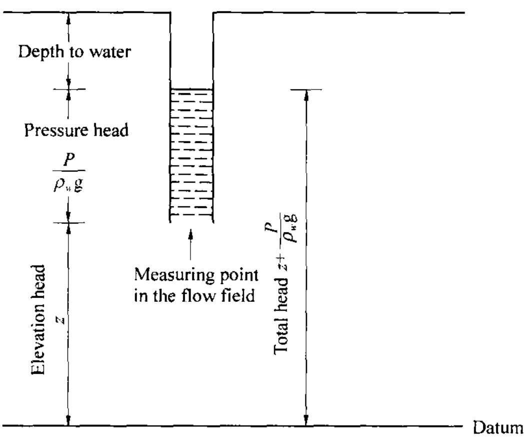


Figure 8.2 Diagram showing elevation, pressure, and total head for a point in the flow field

New Words and Expressions

1.civil engineer 土木工程师
2.acquisition [ˌækwiˈziʃən] *n.* 获得，获得物
3.purification [ˌpjuərifiˈkeiʃən] *n.* 纯化，提纯
4.volumetric [vɔljuˈmetrik] *a.* 测定体积的
5.outlet [ˈautlet, -lit] *n.* 出口
6.cross-sectional [ˈkrɔsˈsekʃənəl] *a.* 横向的
7.manometer [məˈnɔmitə] *n.* 压力计
8.velocity [viˈlɔsiti] *n.* 速度
9.pertinent [ˈpəːtinənt] *a.* 有关的，相干的
10.dimensionless [diˈmenʃənlis] *a.*无因次的
11.term [təːm] *n.* 术语，专有名词
12.specific discharge 比流量，渗透速度
13.gradient [ˈgreidiənt] *n.* 梯度
14.hydraulic [haiˈdrɔːlik] *a.* 与水有关的，水力的，水压的
15.calculus [ˈkælkjuləs] *n.* 微积分学
16.in the terms of 就……而论，在……方面

17.constant of proportionality 比例常数
18.minus ['mainəs] *a.* 负的，减去的
19.granular ['grænjulə] *a.* 颗粒的，形状的
20.laminar['læminə(r)] *a.* 层理的，成层的，薄层的
21.turbulent ['tə:bjulənt] *a.* 紊流的，湍流的，涡旋的
22.circuitous [sə(:)'kju(:)itəs] *a.* 绕行的，迂回的，间接的
23.permeability [ˌpə:miə'biliti] *n.* 渗透性
24.threshold gradient 临界梯度
25.pore [pɔ:, pɔə] *n.* 小孔，气孔
26.superficial [sju:pə'fiʃəl] *a.* 表面的
27.porosity [pɔ:'rɔsiti] *n.* 孔隙率，孔隙度
28.ground water 地下水，潜水
29.designate ['dezigneit] *vt.* 指定(出示)，标明
30.magnitude ['mægnitju:d] *n.* 量，大小，幅度
31.vector ['vektə] *n.* 向量，矢量
32.force potential 势
33.reference to 查阅，参考
34.datum ['deitəm] *n.* data 的单数，数据，资料
35.counterpart ['kauntəpɑ:t] *n.* 副本，相对物
36.piezometer [ˌpaiə'zɔmitə] *n.* 测压管
37.incompressible [ˌinkəm'presəbl] *a.* 不能压缩的
38.flow path 流径，流动通道
39.exert[ig'zə:t] *vt.* 施加(压力等)
40.elevation [ˌeli'veiʃən] *n.* 海拔，高程
41.be concerned with 关心
42.refer to 引用

达西实验定律及现场应用

Henry Darcy 是一位土木工程师，在法国第戎市供水公司工作，值得提及的是，他用获得的资料改进了水净化滤砂设计。利用这方面信息，他建立了水通过砂流动的定律。他的方法经过实验验证，其成果于 1856 年发表。

Darcy 使用的实验装置如图 8.1 所示。在实验中，水通过砂柱，水的体积流量速率 Q 在出口处测定。砂柱的横断面面积已知，它的长度为圆筒中砂的长度。实验时，Darcy 测量了在不同流速下两个压力计水位之间的距离。相关的测量包括 Q，体积流量速率，因次是 L^3/T；A，横断面面积，因次是 L^2；l，砂柱长度，因次是 L；h_1-h_2，压力计读数高差，因次是 L。根据这些测量结果，相关计算是 Q/A，速度 L/T；$(h_1-h_2)/l$，它是无因次量。Q/A 值表示通过单位横断面的体积流动速率，被称为单位流量。无因次量$(h_1-h_2)/l$ 表示在压力计管中水流过的距离为 l 其单位长度上水位高程的改变量。这个术语被称为梯度，或水力梯度，经常用微分 $\partial h/\partial l$ 表示。

根据给出的测量和计算，达西定律可以表示为

$$\frac{Q}{A}=q=\frac{-K(h_1-h_2)}{l}=-K\frac{\partial h}{\partial l} \tag{8.1}$$

式中：q 是单位面积上的体积流动速率，为速度单位；K 是比例常数。由于梯度是无因次量，所以渗透系数 K 为速度单位。负号为人为规定，即流动沿着压力计中水位降低的方向，或者说 h 值从高到低(见图 8.1)。总之，达西定律概括为：流动速度与水力梯度成正比。

达西定律对通过大部分颗粒材料中的水流是有效的。定律表明单位流量和水力梯

度成线性关系。只要水流成层流这一关系就成立。在紊流情况下，水会沿更为迂回线路运动。而另一极端情况，即对于渗透率非常低的材料，要产生渗透须达到最小的临界梯度。

从现场考虑，达西定律要求对四个方面说明：单位流量 q、水位测量、梯度和比例常数 K。

一、达西流速的性质

由定义知，单位流量 q 是试样单位表面积上的体积流动速率。由于水只能通过组成颗粒表面敞开的小孔，所以达西定律中的 q 是一个“表面”流速(量)。因此，我们需要定义一个更真实的流速 v，即在连通的孔隙空间单位面积上体积流动速率。从式(8.1)得到 v 的表达式

$$\frac{Q}{n_e A}=\frac{q}{n_e}=v=-\left(\frac{K}{n_e}\right)\frac{\partial h}{\partial l} \tag{8.2}$$

式中：$n_e A$ 是水流的有效过水面积，n_e 是有效的孔隙度。v 为地下水线性流速或孔隙流速。线性流速 v 总是比表面流速(单位渗流量)大，随着有效孔隙度的减少而增加。最后，梯度 $\partial h/\partial l$ 用 i 表示是很方便的，这样达西定律可以用下列形式表示

$$q=Ki \tag{8.3a}$$

$$Q=KiA \tag{8.3b}$$

$$v=Ki/n_e \tag{8.3c}$$

$$v=q/n_e \tag{8.3d}$$

q 和 v 一样都具有大小和方向，后者和压力计中水位降低的方向一致。q 和 v 为矢量。

二、压力水头：Hubbert 压力势能

如图 8.1 所示，压力计中的水位高程是以试管底某一点为公共点来量测的。这样，达西定律仅和水位差有关，而和水位高度绝对值无关。在这一节，我们感兴趣的不是水位差而是真实的水位测量值。从这一点考虑，我们引入实验室测压管高度的概念。

测压管是一根用来在现场测量水面高程的导管。上端开口用来测量水位，下端开口用来注水，装置如图 8.2 所示，以海平面为 0 点高程。如同 Hubbert(1940 年)所做，图 8.2 中的高程、压强和总水头可用传统的 Bernoulli 方程说明。该方程指出，在稳定流条件下，密闭系统中不可压缩流体总能量沿流径在任何位置都是常数。表示为

$$gz+\frac{P}{\rho_w}+\frac{v^2}{2}=\text{常量} \tag{8.4}$$

式中：g 是重力加速度，z 是测压管底部的高程，P 是水柱施加的压强，ρ_w 是流体密度，而 v 是流速。

Reading Material

Physical Interpretation of Darcy's Proportionality Constant

By experimentally varying fluid density, viscosity, and the geometrical properties of sands, Hubbert (1956) reported that Darcy's proportionality constant K varied in the following manner

$$K \propto \rho_w$$
$$K \propto 1/\mu$$
$$K \propto d^2$$

where, μ is viscosity and d is the mean grain diameter of the sand. This can be expressed as

$$K = K^* \frac{\rho_w d^2}{\mu} \tag{8.5}$$

where, K^* is yet another constant of proportionality containing variables not yet evaluated. It is obvious at this point that Darcy's K is a function of both properties of the medium and properties of the fluid.

Insight into the parameter K^* may be obtained by comparing Darcy's law with the Hagen-Poiseuille equation long known to govern laminar flow through small diameter passages. Incorporating Eq. 8.5 into Darcy's law gives

$$q = \frac{-K^* \rho_w d^2}{\mu} \text{grad } b \tag{8.6}$$

Whereas the Hagen-Poiseuille equation is

$$q = \frac{-N \rho_w g R^2}{\mu} \text{grad } b \tag{8.7}$$

where, N is a dimensionless shape factor relating to the geometry of passage and R is the diameter of passage. Eq. 8.6 and Eq.8.7 are perfectly equivalent if the diameter of passage R is equivalent to the mean grain diameter so that the constant K^* is equal to the product of the dimensionless shape factor N and the acceleration due to gravity g. Making this analogy, Darcy's constant of proportionality is expressed as

$$K = \frac{N \rho_w g d^2}{\mu} = \frac{k \rho_w g}{\mu} \tag{8.8}$$

where, Nd^2 characterizes the properties of the medium and ρ_w/μ the properties of the fluid. The parameter K is referred to as the hydraulic conductivity and contains properties of both the medium and the fluid, and the parameter k is referred to as the intrinsic permeability (equal to Nd^2) and contains properties of the medium only. The hydraulic conductivity with units of velocity characterizes the capacity of a medium to transmit water, whereas the permeability with units L^2 characterizes the capacity of the medium to transmit any fluid.

The term "hydraulic conductivity" is used most frequently in ground water literature when dealing with the single water phase. The term "permeability" is used in the petroleum industry where the fluids of interest are oil, gas, and water. Typical values of permeability in square centimeters or square meters are quite small so that the "darcy" is commonly defined as a unit of permeability. For a material of 1-darcy permeability, a pressure differential of one atmosphere will produce a flow rate of 1 cc (cubic centimeter) per second for a fluid with 1-centipoise viscosity through a cube having sides 1 cm in length. One darcy is approximately equal to 10^{-8} cm^2 or, for water of normal density and viscosity, 10^{-3} cm/s. For tight materials, the millidarcy (md) is used, where 1 md equals 0.001 darcys, or approximately 10^{-6} cm/s.

It is now possible to state yet another form of Darcy's law commonly used in the petroleum industry. Incorporating our definition of the constant of proportionality K, the hydraulic head b, and the gradient of the head h, Darcy's law becomes

$$q = \frac{N\rho_w g d^2}{\mu} \text{grad}\left(z + \frac{P}{\rho_w g}\right) \tag{8.9}$$

For those cases where all piezometers are bottomed at the same elevation in a flat lying bed, z is a constant so its derivative goes to zero. Taking both the fluid density and the acceleration of gravity as constants, Eq.8.9 becomes

$$q = \frac{Nd^2}{\mu} \text{grad}\, P = -\frac{k}{\mu} \text{grad}\, P \tag{8.10}$$

This expression is quite convenient when dealing with multiphase fluid systems where the permeability k by definition is invariant with respect to whatever fluid is being considered.

New Words and Expressions

1.experimentally [iksperi'mentəli] *adv.* 实验上，用实验方法
2.viscosity [vis'kɔsiti] *n.* 黏质，黏性
3.geometrical [dʒiə'metrik(ə)l] *a.* 几何的，几何学的
4.mean[mi:n, min] *a.* 平均的
5.evaluate [i'væljueit] *vt.* 对……估价，对……作评价
6.medium['mi:djəm] *n.* 媒介，介质
7.insight into 洞察
8.passage ['pæsidʒ] *n.* 通道，通路
9.incorporate [in'kɔ:pəreit] *vt.* 合并
10.equivalent [i'kwivələnt] *a.* 相等的，相当的，等效的
11.product ['prɔdəkt] *n.* 乘积
12.characterize ['kæriktəraiz] *vt.* 描绘，刻画，具有……特征
13.hydraulic conductivity 渗透系数
14.intrinsic permeability 渗透率
15.transmit [trænz'mit] *vt.* 传送，透过
16.water phase 水相
17.petroleum [pi'trəuliəm] *n.* 石油
18.differential [ˌdifə'renʃəl] *n.* 差别，差异
19.cubic ['kju:bik] *a.* 立方体的，立方的
20.cube [kju:b] *n.* 立方体，立方
21.centipoise ['sentipɔiz] *n.* 百分之一泊(黏

滞性单位)，厘泊

22.tight [tait] *a.* 致密的，紧密的，不漏水(不透气)的

23.millidarcy ['milidɑːsi] *n.* 毫达西

24.bottom ['bɔtəm] *vt.* 测量深浅

25.derivative [di'rivətiv] *n.* 导数，微商

26.multiphrase ['mʌltifeiz] *a.* 多相的

27.invariant [in'vɛəriənt] *n* . 不变式，不变量

28.with respect to 有关

阅读材料

达西渗透系数的物理解释

通过实验改变流体密度、黏滞系数和砂粒的几何性质，Hubbert 于 1956 年在报告中指出达西的渗透系数 K 可以变换为下列形式

$$K \propto \rho_w$$

$$K \propto 1/\mu$$

$$K \propto d^2$$

式中：μ 是黏滞系数，d 是砂颗粒的平均粒径。则 K 表示为

$$K = K^* \frac{\rho_w d^2}{\mu} \tag{8.5}$$

式中：K^*是含有未定变量的另一比例常数。很明显，达西定律中的 K 值是表示流经介质特性和流体特性的函数。

加以观察，把达西定律与 Hagen-Poiseuille 方程加以对比可得到参数 K^*，一般来说 K^*适用于小颗粒层流条件。把公式(8.5)代入达西定律

$$q = \frac{-K^* \rho_w d^2}{\mu} \text{grad } b \tag{8.6}$$

而 Hagen-Poiseuille 公式是

$$q = \frac{-N \rho_w g R^2}{\mu} \text{grad } b \tag{8.7}$$

式中：N 是无因次形状系数，与通道几何形状有关；R 是通道的直径。如果通道直径 R 等于平均颗粒粒径，常量 K^*就等于无因次形状系数 N 与重力加速度 g 的乘积，则公式(8.6)和公式(8.7)完全等价。通过上述分析，Darcy 的渗透系数又可表示为

$$K = \frac{N \rho_w g d^2}{\mu} = \frac{k \rho_w g}{\mu} \tag{8.8}$$

式中：Nd^2 表示介质特性，ρ_w/μ表示流体性质。参数 K 被称为渗透系数，它包括了介质和流体两方面性质，参数 k 被称为固有渗透率(等于 Nd^2)，只包括介质特性。以速度为单位的渗透系数表示了介质透水的能力，而以 L^2 为单位的渗透率则表示了介质透过任何流体的能力。

当仅与水有关时，术语“渗透系数”常用于地下水文献。而“渗透率”则用于以

油、气和水为流体的石油工业中。在 1 个平方厘米或平方米面积内渗透率的标准值相当小，所以把单位渗透率通常叫“达西”。对有 1 达西渗透率的材料，使 1 厘泊黏度的流体通过每边长为 1 厘米的立方体,一个大气压差会使流体产生每秒 1cc(立方厘米)的流量。1 达西大约相当于 10^{-8}cm^2，或者对正常密度和黏度的水相当于 10^{-3}cm/s。对于致密材料使用毫达西(md)，这时 1 毫达西相当于 0.001 达西，或大约为 10^{-6}cm/s。

现在，可以提出另外一种仍常用于石油工业中的达西定律形式。把渗透系数 K、水头 b、水头梯度 h 加以整理，达西定律变为

$$q=\frac{N\rho_w g d^2}{\mu}\mathrm{grad}\left(z+\frac{P}{\rho_w g}\right) \tag{8.9}$$

当河床平坦时，测压管与河床高程相同，z 是常数，因此其导数为 0。认为流体密度和重力加速度是常数，则公式(8.9)可变为：

$$q=\frac{Nd^2}{\mu}\mathrm{grad}\,P=-\frac{k}{\mu}\mathrm{grad}\,P \tag{8.10}$$

这个公式在处理多相流体系统时相当方便，其中渗透系数 k 被认为对任何流体都是常数。

Unit 9

Text

Subsurface Aqueous System and Solute

1 Introduction to Aqueous Systems

Mass can exist in the subsurface as ① separate gas or solid phases, for example, CO_2 gas in the soil zone or minerals that form the porous medium; ② a separate liquid phase, for example, crude oil and liquid organic contaminants; or ③ mass dissolved in the water itself (that is, solutes), for example, Na^+or Cl^-. While all these occurrences are important in a geologic context, hydrogeologists have typically focused on the third type. It is for this reason that our discussion will concentrate on mass dissolved in water. We cannot, however, avoid treating the nonaqueous phase liquids, gases, and solids because these are often the sources of solutes in ground water or potential contaminants.

Mass occurring in water as ions, molecules, or solid particles not only undergoes transport but also reactions, which redistribute mass among various ion species, or between the liquid and solid phases. Our list of reactions is not exhaustive, it includes the most important ones affecting the chemistry of ground water. These chemical processes operate in a system consisting of one or more solid phases, an aqueous solution phase, and a gas phase (Fig.9.1) and redistribute mass within a phase or between phases.

Most inorganic substances are electrolytes, dissolving in water to form ions. Positively charged species, such as Ca^{2+} or K^+, are called cations. Negatively charged species, such as HCO^-_3 or Cl^- are called anions. Complex ions form by combining simpler cations and anions. Organic substances can also dissolve to form organic cations or anions. However, organic liquids are usually nonelectrolytes and dissolve in water as nonionic molecules. In the aqueous phase, the distribution of species is described in terms of a molar concentration or an activity, which is an effective concentration accounting for chemical nonidealities in reactions. The notation adopted throughout the book is to represent molar concentrations with round brackets for example (Ca^{2+}) and activities with square brackets [Ca^{2+}]. Gases are represented in terms of partial pressures of constituent gases (for example, P_{CO_2}) or in nonideal systems by fugacities f_{CO_2}. Solid phase compositions (Fig.9.1) are represented as mole fractions and activities.

Concentration scales quantitatively describe mass distributions. The next two sections

will examine the commonly used scales, and provide scale conversions for concentrations.

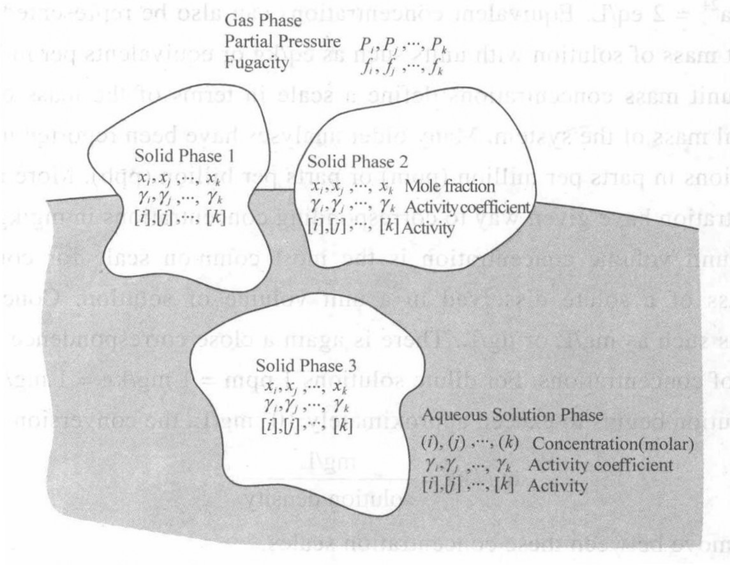


Figure 9.1 Generalized model of a chemical system for ground water at some temperature and pressure (modified from Stumm and Morgan, 1981, Aquatic Chemistry)

2 Aqueous Solution Phase

Molar concentration (M) defines the number of moles of a species per liter of solution (mol/L). A mole is the formula weight of a substance expressed in grams. For example, a 1 liter solution containing 1.42 g of Na_2SO_4 has a (Na_2SO_4) molarity of $1.42/(2 \times 22.99 + 32.06 + 4 \times 16.00)$ or 0.010 M. Because Na_2SO_4 dissociates completely in water according to the following reaction

$$Na_2SO_4 = 2Na^+ + SO_4^{2-}$$

the molar concentrations of Na^+ and SO_4^{2-} are 0.02 and 0.01 M, respectively. This reaction states that 1 mole of Na_2SO_4 dissolves to produce 2 moles of Na^+ and 1 mole of SO_4^{2-}. Because substances react in molar proportions, many of the thermodynamic calculations use concentrations expressed in moles.

Molar concentration (m) defines the number of moles of a species per kilogram of solvent (mol/kg). This scale for concentrations in dilute solutions is almost the same as molar concentrations because a 1 liter solution has a mass of approximately 1 kg. For more concentrated solutions, the two scales become increasingly different. Pytkowlcz provides equations for converting between these two scales.

Equivalent charge concentration is the number of equivalent charges of an ion per liter of solution with units such as eq/L or meq/L. The equivalent charge for an ion is equal to the number of moles of an ion multiplied by the absolute value of the charge. For example, with a

singly charged species such as Na^+, 1 M Na^+ =1 eq/L, and with a doubly charged species such as Ca^{2+}, 1 M Ca^{2+} = 2 eq/L. Equivalent concentrations can also be represented as equivalent charges per unit mass of solution with units such as eq/kg or equivalents per million (epm).

Mass per unit mass concentrations define a scale in terms of the mass of a species or element per total mass of the system. Many older analyses have been reported using this scale with concentrations in parts per million (ppm) or parts per billion (ppb). More recently, these units of concentration have given way to corresponding concentrations in mg/kg or μg/kg.

Mass per unit volume concentration is the most common scale for concentration. It defines the mass of a solute dissolved in a unit volume of solution. Concentrations are reported in units such as mg/L or μg/L. There is again a close correspondence between these last two scales of concentrations. For dilute solutions 1 ppm = 1 mg/kg = 1 mg/L. As the total salinity of a solution begins to exceed approximately 10^4 mg/L, the conversion equation

$$\text{mg/kg} = \frac{\text{mg/L}}{\text{solution density}} \tag{9.1}$$

is necessary to move between these concentration scales.

Concentration conversions involve a few simple equations. The most common scale change takes the reported values of chemical analyses in mg/L (also mg/kg or ppm) and converts them to molar concentrations.

$$\text{Molarity} = \frac{\text{mg/L} \times 10^{-3}}{\text{formula weight}} \tag{9.2}$$

Conversion from mg/L to meq/L is sometimes necessary to represent chemical data graphically or to check chemical analyses. This conversion equation is

$$\text{meq/L} = \frac{\text{mg/L}}{\text{formula weight/charge}} \tag{9.3}$$

As an example in the conversion of scales, consider the following.

3 Example 9.1

Given a water analysis with an SO_4^{2-} concentration of 85.0 mg/L, express this concentration first in terms of molarity and second in meq/L.

$$\text{mol/L} = \frac{85 \times 10^{-3}}{32.06 + 4 \times 16.0} = 0.89 \times 10^{-3}$$

$$\text{meq/L} = \frac{85}{(32.06 + 4 \times 16.0)/2} = 1.77$$

4 Gas and Solid Phases

Although interest in most chemical investigations is with the water, the gas and solid phases are important because of the possible interactions with the solution phase. Further, the volatiles associated with some organic liquids may be contaminants. In thermodynamic

calculations, concentrations of gases are given as partial pressures. In a mixture of gases at a fixed temperature and in equilibrium with the aqueous phase, the partial pressure of a gas is the pressure the gas would exert if it occupied the whole volume of the mixture by itself. For example, CO_2 gas in the atmosphere has a P_{CO_2} of about $10^{-3.5}$ atmospheres (atm). It is also quite common to report gas concentrations using a scale such as ppm or mg/L, and so on, when reporting the results of laboratory determinations of gas compositions.

Concentrations for solids are represented as a mole fraction, which is the ratio of the number of moles of the phase of interest to the total number of moles in the system. However, thermodynamic calculations often do not require the solid phase concentrations because by convention the solid phase concentration or activity for a pure solid is one.

New Words and Expressions

1.aqueous ['eikwiəs] *a.* 水的，含水的
2.aqueous system 水系统，含水体系
3.mass [mæs] *n.* 物质
4.subsurface ['sʌb'səːfis] *a.* 地面下的
5.porous ['pɔːrəs] *a.* 多孔的
6.organic [ɔː'gænik] *a.* 有机的
7.contaminant [kən'tæminənt] *n.* 致污物，污染物
8.organic contaminant 有机污染物
9.solute ['sɔljuːt] *n.* 溶解物，溶质
10.occurrence [ə'kʌrəns] *n.* 出现，存在
11.context ['kɔntekst] *n.* 前后关系，关联
12.hydrogeologist *n.* 水文地质学家，水文地质工作者
13.nonaqueous ['nɔn'eikwiəs] *a.* 非水的
14.ion ['aiən] *n.* 离子
15.molecule ['mɔlikjuːl, 'məu-] *n.* 分子
16.undergo[ˌʌndə'gəu] *vt.* 经历，遭受，忍受
17.transport [træns'pɔːt] *vt.* 传送，运输
18.reaction [ri(ː)'ækʃən] *n.* 反应
19.redistribute [ˌriːdis'tribju(ː)t] *vt.* 重新分配，重新分布
20.exhaustive [ig'zɔːstiv] *a.* 消耗的，使枯竭的
21.inorganic [ˌinɔː'gænik] *a.* 无生物的，无机的
22.electrolyte [i'lektrəulait] *n.* 电解液
23.charged species 带电粒子
24.cation ['kætaiən] *n.* 阳离子
25.anion ['ænaiən] *n.* 阴离子
26.nonelectrolyte [ˌnɔni'lektrəulait] *n.* 非电解质
27.species ['spiːʃiz] *n.* 种类
28.nonionic [ˌnɔnai'ɔnik] *a.* 在溶液中不分解成离子的
29.molar ['məulə] *a.* 摩尔的
30.activity [æk'tiviti] *n.* 活性
31.concentration [ˌkɔnsen'treiʃən] *n.* 浓度
32.account for 说明，证明
33.nonideal [ˌnɔnai'diəl] *a.* 非理想的
34.notation [nəu'teiʃən] *n.* 记号，标志
35.fugacity [fju(ː)'gæsiti] *n.* 逸性，逸度，有效压力
36.mole['məul] *n.* 摩尔，克分子(量)
37.fraction['frækʃən] *n.* 分数
38.quantitatively ['kwɔntitətivli] *adv.* 数量上
39.partial pressure 分压
40.solution [sə'luːʃən] *n.* 溶液
41.formula weight 式量，化学式量，分子量
42.gram [græm] *n.* 克
43.molarity [məu'læriti] *n.* 摩尔浓度
44.dissociate [di'səuʃieit] *v.* 分离，游离
45.thermodynamic [ˌθəːməudai'næmik] *a.*

热力学的
46.molal ['məuləl] *a.* 重量摩尔的，重模的
47.solvent ['sɔlvənt] *n.* 溶剂
48.dilute [dai'lju:t, di'l-] *a.* 稀释的
49.increasingly [in'kri:siŋli] *adv.* 日益，愈加
50.equivalent charge 当量电荷
51.multiply ['mʌltipli] *vt.* 乘，使相乘
52.doubly['dʌbli] *adv.* 两倍地，双重地
53.parts per million 百万分率，百万分之几
54.parts per billion 十亿分率，十亿分之几
55.salinity [sə'liniti] *n.* 盐分，盐度
56.equation[i'kweiʃən] *n.* 方程式，等式
57.formula ['fɔ:mjulə] *n.* 公式
58.graphically ['græfikəli] *adv.* 用图表表示
59.volatile ['vɔlətail] *n.* 挥发物
60.equilibrium [ˌi:kwi'libriəm] *n.* 平衡，均衡
61.by convention 按照惯例

地下含水系统及其溶质

一、含水系统介绍

地下物质有三种形式：①游离的气态或固态，例如在土壤带中存在 CO_2 气体或形成多孔介质的；②游离的液态形式，如原油或液态有机污染物；③水中的溶解物(即溶质)，如 Na^+或 Cl^-。尽管这些存在形式在地质历史中很重要，但水文地质学家特别关注第三种形式。正是这一原因，我们也重点讨论水中的溶解物。然而，我们不可避免地要涉及非水相的液态、气态和固态，因为它们通常是地下水中溶质的来源或潜在污染物。

以离子、分子和固体颗粒形式存在于水中的物质不仅可以移动而且还会发生化学反应，通过化学反应使各种离子重新调整或液态与固态物质间产生再分配。我们列出的化学反应并不是消耗性的，它包含影响地下水化学成分的一些最重要方面。这些化学反应会在由一种或多种固态物、水溶液和气态物构成的系统中发生(见图 9.1)，并在一种形态或两种形态间发生物质再分配。

大多数无机物发生电解，溶于水形成离子。带正价电离子如 Ca^{2+}或 K^+称为阳离子。带负价电离子如 HCO_3^-或 Cl^-称为阴离子。复杂的离子形式是由较简单的阴阳离子连接而成的。有机物也可以溶解形成有机阳离子或阴离子。然而，有机液体通常是非电解质，在水中溶解成非电离的分子形式。在溶液中，离子的分布常用摩尔浓度或活性度来表示，活性度是一种有效浓度，说明在化学反应中并不理想。在书中用圆括号表示摩尔浓度如(Ca^{2+})，用方括号表示活性度如$[Ca^{2+}]$。气态物以构成气体组成物的分压表示(如 P_{CO_2})或在非理想系统中用有效压力 f_{CO_2} 表示。固态物的组成(见图 9.1)用克分子分数和活性度表示。

浓度的大小可以在数量上表示物质的分布。以常用的刻度比尺来检查下面两部分，并给出刻度比尺与浓度的转换关系。

二、水溶液

摩尔浓度(M)定义为每升溶液中物质的摩尔数(mol/L)。1 mole 是以克表示的物质分子量。例如，在含有 1.42 克 Na_2SO_4 的 1 升溶液中(Na_2SO_4)摩尔浓度为 $1.42/(2\times22.99+32.06+4\times16)$或 0.010 M。$Na_2SO_4$ 在水中完全溶解化学反应式为

$$Na_2SO_4 = 2Na^+ + SO_4^{2-}$$

所以 Na^+和 SO_4^{2-} 的摩尔浓度分别为 0.02 M 和 0.01 M。这个反应式说明 1mole Na_2SO_4溶解产生 2 moles Na^+和 1mole SO_4^{2-}。因为物质按摩尔比例发生反应，许多热力学计算都用摩尔来表示浓度。

摩尔浓度(m)也可指每千克溶剂中物质的摩尔数(mol/kg)。在稀释溶液中这一浓度比率几乎和摩尔浓度有相同比率，因为 1 升溶液的质量大约等于 1 kg。溶液浓度增大，这两个比率逐渐不同。Pytkowicz 给出这两个比率的换算公式。

当量电荷浓度是每升溶液中离子当量电荷的数目，使用单位如 eq/L(当量/升)或 meq/L(毫克当量/升)。离子的当量电荷等于离子的摩尔数与电荷绝对值乘积。例如，对于一个电荷离子 Na^+，1 M Na^+=1eq(当量)/L,而对于双电荷离子 Ca^{2+}，1 M Ca^{2+}=2 eq/L。当量浓度也可以表示为单位质量溶液中的当量电荷，单位为 eq/kg 或百万当量(epm)。

物质的单位质量浓度定义为物质或元素质量与系统总质量的比值。许多传统分析记录这个比率以百万分率(ppm)或十亿分率(ppb)为单位表示浓度。近来，这些浓度单位已逐渐被以 mg/kg(毫克/公斤)或μg/kg(微克/公斤)表示的浓度单位代替。

单位体积质量浓度是最常用的浓度比率尺度。它定义为单位体积溶液中溶解的溶质质量。浓度的单位用 mg/L 或μg/L 表示。上面这两个浓度单位之间存在密切的关系。对于稀释溶液，1 ppm=1 mg/kg=1 mg/L。当溶液总盐度开始超过大约 10^4 mg/L 时，换算方程为

$$\mathrm{mg/kg} = \frac{\mathrm{mg/L}}{\text{溶液密度}} \tag{9.1}$$

两个浓度单位之间的转化是必要的。

浓度转化包含一些简单公式。最常用的单位转化采用化学分析得到的数值以 mg/L 表示(也可以是 mg/kg 或 ppm)，这些数据被转化为摩尔浓度

$$\text{摩尔浓度} = \frac{\mathrm{mg/L} \times 10^{-3}}{\text{分子量}} \tag{9.2}$$

有时，为了用图表表示化学数据或检验化学分析结果，将 mg/L 转化为 meq/L 是必要的。转换方程式是

$$\mathrm{meq/L} = \frac{\mathrm{mg/L}}{\text{分子量/电量}} \tag{9.3}$$

下面是转化的例子。

三、例 9.1

通过水分析知 SO_4^{2-} 浓度为 85.0 mg/L，试分别用摩尔浓度和 meq/L 浓度表示。

$$\mathrm{mol/L} = \frac{85 \times 10^{-3}}{32.06 + 4 \times 16.0} = 0.89 \times 10^{-3}$$

$$\mathrm{meq/L} = \frac{85}{(32.06 + 4 \times 16.0)/2} = 1.77$$

四、气体和固体

尽管多数化学调查与水有关，但气体和固体与溶液也会发生交互作用，故两者也很

重要。而且，一些有机液态挥发物可能受到污染。在热力学计算中，气体浓度定义为分数压力。假定气体占有整个混合物的体积，对于固定温度下的气体混合物中或溶液达到平衡时，气体分数压是气体施加的压力。例如，大气中的 CO_2 气体具有大约 $P_{CO_2}=10^{-3.5}$ 大气压(atm)。在记录实验室测定气体成分的结果时，使用如 ppm 或 mg/L 等单位记录气体浓度是很常见的。

固体浓度用摩尔分数表示，摩尔分数等于相关物质的摩尔数与系统总摩尔数的比。然而，热力学计算并不要求固体浓度，因为按常规固体浓度或活性对纯固相来说是一回事。

Reading Material

Structure of Water and Water Reaction for Mass

1 Structure of Water and the Occurrence of Mass in Water

The structure of water is important in controlling the chemistry of ground water because of its influence on the solubility of solids and organic liquids. The water molecule is comprised of two hydrogen atoms and one oxygen atom. Shared electrons form covalent bonds between atoms. Hydrogen atoms are located asymmetrically with respect to the oxygen atom (Fig.9.2(a)). Because of this structure and the covalent bonding, the electrical center of the negative charges(electrons)has a different location than does that of the positive charges. This separation makes the molecule polar in terms of electrical charge. When a molecule is perfectly symmetrical (e.g., carbon tetrachloride, benzene, and other hydrocarbons), there is no charge separation and the molecule is nonpolar.

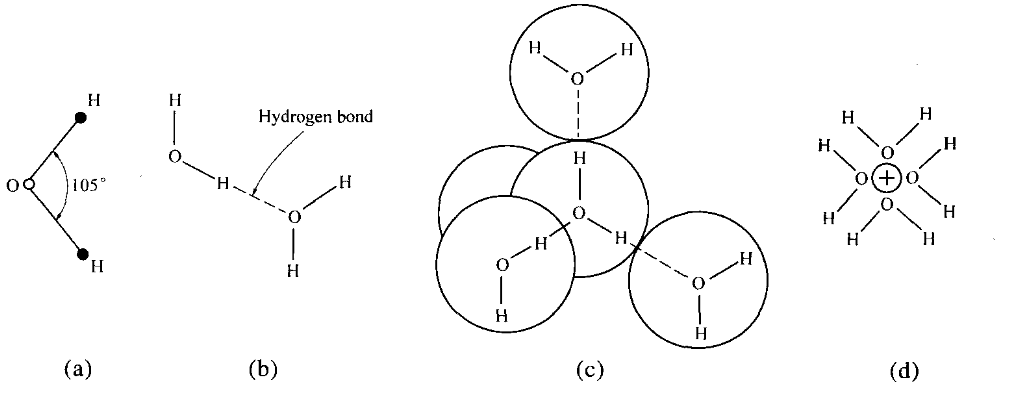


Figure 9.2 Essential features of the structure of water and adjustments due to the presence of an ion (adapted from Pytkowicz, 1983)

(a) the position of the hydrogen and oxygen atoms in the polar water molecule; (b) hydrogen bonding between water molecules, giving rise to (c) the tetrahedral structure of water; (d) water molecules rearrange themselves around a cation due to the polar nature of the water

The water molecules are joined in a series of hydrogen bonds (Fig.9.2(b)) formed by electrostatic interaction between a hydrogen and an oxygen atom. As a result of these interactions, the water molecules form a tetrahedral network (Fig.9.2(c)) creating a series of larger molecules. This molecular structure explains some of the unique characteristics of water such as its freezing and boiling points.

This structure also contributes to the relative solubility of electrolytes and the insolubility of nonelectrolytes in aqueous solution. From an energetic viewpoint, it is advantageous for charged species (eg. ions or molecules) to be accommodated in the water structure, overcoming the energy that tends to keep atoms in a solid or another liquid. In water, a charged species forces a local rearrangement in the structure (Fig.9.2(d)). Water molecules immediately adjacent bind to the charged species. Those nearby reorient themselves because of the charge. The zone of influence immediately adjacent to the ion is known as the hydration sheath. A so-called random region separates the hydration sheath from the bulk solution. Within the random region, the water molecules are less oriented than they are in either the bulk solution or the hydration sheath. In the case of an uncharged species, such as many nonpolar organic molecules, it is energetically more favorable for mass to remain in an organic liquid rather than the aqueous solution. The nonpolar molecule in effect has to jam itself into the spaces in the water structure. Thus, the structure of water, on the one hand, favors the solubility of electrolytes yet, on the other hand, contributes to the low solubility of many nonpolar, organic molecules.

2 Equilibrium Versus Kinetic Descriptions of Reactions

The state of chemical equilibrium for a closed system describes a position of maximum thermodynamic stability. At equilibrium, there is no chemical energy available to alter the relative distribution of mass between the reactants and products in a reaction. Away from equilibrium, energy is available to drive a system spontaneously toward equilibrium by allowing the reaction to progress.

Theoretical approaches are useful for modeling the chemical composition of a solution at equilibrium. However, these methods provide no information about the time required to reach equilibrium or the reaction pathways involved. A different approach based on kinetic models of reaction is required to provide this information.

Ground water can be thought of as a partial equilibrium system. Some reactions are at equilibrium and are best described by equilibrium concepts. However, other reactions are not at equilibrium and are described best by kinetic concepts. How a reaction is finally modeled depends upon its rate. An equilibrium reaction is "fast" in relation to the mass transport processes that are working to change concentrations. A kinetic reaction is "slow" in relation to the transport processes.

New Words and Expressions

1.TBE =Total Binding Energy (核的)总结合能
2.solubility [ˌsɔlju'biliti] *n.* 溶解度，溶解性
3.hydrogen ['haidrəudʒən] *n.* 氢
4.covalent [kəu'veilənt] *a.* 共有原子价的，共价的
5.covalent bond 共价键
6.asymmetrically [ˌæsi'metrikəli] *adv.* 不对称地
7.with respect to 关于，至于
8.tetrahedral ['tetrə'hedrəl] *a.* 有四面的，四面体的
9.polar ['pəulə] *a.* 极性的
10.electrical charge 电荷
11.symmetrical [si'metrikəl] *a.* 对称的，相称的
12.tetrachloride [ˌtetrə'klɔ:raid] *n.* 四氯化物
13.benzene ['benzi:n, ben'zi:n] *n.* 苯
14.hydrocarbon [ˌhaidrəu'kɑ:bən] *n.* 烃，碳氢化合物
15.nonpolar [ˌnɔn'pəulə] *a.* 无极的
16.electrostatic [i'lektrəu'stætik] *a.* 静电的，静电学的
17.interaction [ˌintər'ækʃən] *n.* 交互作用，交感
18.electrolyte [i'lektrəulait] *n.* 电解，电解液
19.insolubility [inˌsɔlju'biliti] *n.* 不溶性
20.rearrangement [ˌri:ə'reindʒmənt] *n.* 重新配置，调整
21.adjacent [ə'dʒeisənt] *a.* 邻近的，接近的
22.reorient [ˌri:'ɔ:rient] *v.* 再改方向，再定方位
23.hydration [hai'dreiʃən] *n.* 水合，水合作用
24.sheath [ʃi:θ] *n.* 鞘，外壳
25.hydrated sheath 水化层
26.ion sheath 离子覆盖，离子层
27.bulk solution 大体积溶液
28.in the case of 在……的情况
29.in effect 有效
30.jam [dʒæm] *vt.* 挤进，使塞满
31.kinetic [kai'netik] *a.* 动力(学)的，反应动力学的
32.reaction [ri(:)'ækʃən] *n.* 反应
33.stability [stə'biliti] *n.* 稳定性
34.reactant [ri:'æktənt] *n.* 反应物
35.spontaneously [spɔn'teinjəsli, -niəsli] *adv.* 自然地，本能地
36.theoretical [θiə'retikəl] *a.* 理论的
37.pathway ['pɑ:θwei] *n.* 路径，通道(路)
38.in relation to 关于

阅读材料

水结构和水对物质的反应

一、水结构和水对物质的溶解

水的结构在控制地下水的化学性质上非常重要，原因是它影响到固体和有机液体的溶解度。水分子由 2 个氢原子和 1 个氧原子组成。公有电子形成了原子间的共价键。氢原子分布与氧原子不对称(见图 9.2(a))。由于这种结构和共价键使负电荷(电子)的电子中心与正电荷的电子中心位置不同。根据电荷情况这种分离使分子产生极性。当一个分子

完全对称(如四氯碳化物、苯和其他碳氢化合物)时，不存在电荷分离，分子是无极性的。

水分子由一系列氢键相连接(见图 9.2(b))，而氢键是由一个氢原子和一个氧原子通过静电交互作用形成的。静电交互作用的结果使水分子形成了四面体网络(见图 9.2(c))，生成了一系列较大的分子。这样的分子结构解释了水的一些独有特征，如水的冰点和沸点。

这种结构也有利于水溶液中电解液的相对溶解度和非电解液的不溶性。从能量的观点看，对适应于水结构带电物质(离子和分子)来说是有利的，在固体或液体材料中可以克服使其保持原子状态的能量。在水中，带电物质迫使结构局部重新排列(见图 9.2(d))。邻近的水分子会立刻被吸附到带电物质上。因为电荷影响，附近的那些分子会再定位。临近离子的直接受影响区域被称为水化层。所谓的随机区可从大体积溶液中把水化层分离出来。相对于在大体积溶液中或者在水化层中，水分子在随机区内很少固定方位。不带电材料，如许多无极性的有机物分子，从能量考虑，更适合存在于有机液体中而不是水溶液中。实际上，无极性分子必然塞入水结构空间中。这样，一方面水结构有助于电解液的溶解性，另一方面也会使许多无极性的有机分子溶解性降低。

二、平衡与动力学反应描述

对于一个密闭系统化学平衡状态所描述的是最大热力学稳定状态方式。处于平衡状态时，在化学反应中生成物和反应物之间没有化学能来改变物质的相对分配。一旦失去平衡，能量会自然地通过反应进程推动系统趋向平衡状态。

可用理论方法来模拟在平衡状态时溶液的化学结构。然而，这些方法没能提供达到平衡所要的时间信息或包含的反应路径。按动力学反应模型则要求用不同方法给出这些信息。

地下水可以被看做一个局部平衡系统。一些反应处于平衡状态，可以用平衡概念很好地描述。然而，其他反应处于不平衡状态，最好用动力学概念描述。一个反应最终被如何模拟将取决于反应速度。平衡反应在改变浓度的物质转移过程方面很快。动力学反应的转移过程很慢。

Unit 10

Text

Rock Mass Classification

During the feasibility and preliminary design stages of a project, when very little detailed information on the rock mass and its stress and hydrologic characteristics is available, the use of a rock mass classification scheme can be of considerable benefit. At its simplest, this may involve using the classification scheme as a check-list to ensure that all relevant information has been considered. At the other end of the spectrum, one or more rock mass classification schemes can be used to build up a picture of the composition and characteristics of a rock mass to provide initial estimates of support requirements, and to provide estimates of the strength and deformation properties of the rock mass.

It is important to understand that the use of a rock mass classification scheme does not (and cannot) replace some of the more elaborate design procedures. However, the use of these design procedures requires access to relatively detailed information on in situ stresses, rock mass properties and planned excavation sequence, none of which may be available at an early stage in the project. As this information becomes available, the use of the rock mass classification schemes should be updated and used in conjunction with site specific analyses.

1 Engineering Rock Mass Classification

Rock mass classification schemes have been developing for over 100 years since Ritter (1879) attempted to formalise an empirical approach to tunnel design, in particular for determining support requirements. While the classification schemes are appropriate for their original application, especially if used within the bounds of the case histories from which they were developed, considerable caution must be exercised in applying rock mass classifications to other rock engineering problems.

Summaries of some important classification systems are presented in this chapter, and although every attempt has been made to present all of the pertinent data from the original texts, there are numerous notes and comments which cannot be included. The interested reader should make every effort to read the cited references for a full appreciation of the use, applicability and limitations of each system.

Most of the multi-parameter classification schemes (Wickham et al (1972), Bieniawski (1973, 1989) and Barton et al (1974)) were developed from civil engineering case histories in

which all of the components of the engineering geological character of the rock mass were included. In underground hard rock mining, however, especially at deep levels, rock mass weathering and the influence of water usually are not significant and may be ignored. Different classification systems place different emphases on the various parameters, and it is recommended that at least two methods be used at any site during the early stages of a project.

2 Terzaghi's Rock Mass Classification

The earliest reference to the use of rock mass classification for the design of tunnel support is in a paper by Terzaghi (1946) in which the rock loads, carried by steel sets, are estimated on the basis of a descriptive classification. While no useful purpose would be served by including details of Terzaghi's classification in this discussion on the design of support, it is interesting to examine the rock mass descriptions included in his original paper, because he draws attention to those characteristics that dominate rock mass behaviour, particularly in situations where gravity constitutes the dominant driving force. The clear and concise definitions and the practical comments included in these descriptions are good examples of the type of engineering geology information, which is most useful for engineering design.

Terzaghi's descriptions are:

Intact rock contains neither joints nor hair cracks. Hence, if it breaks, it breaks across sound rock. On account of the injury to the rock due to blasting, spalls may drop off the roof several hours or days after blasting. This is known as a spalling condition. Hard, intact rock may also be encountered in the popping condition involving the spontaneous and violent detachment of rock slabs from the sides or roof.

Stratified rock consists of individual strata with little or no resistance against separation along the boundaries between the strata. The strata may or may not be weakened by transverse joints. In such rock the spalling condition is quite common.

Moderately jointed rock contains joints and hair cracks, but the blocks between joints are locally grown together or so intimately interlocked that vertical walls do not require lateral support. In rocks of this type, both spalling and popping conditions may be encountered.

Blocky and seamy rock consists of chemically intact or almost intact rock fragments which are entirely separated from each other and imperfectly interlocked. In such rock, vertical walls may require lateral support.

Crushed but chemically intact rock has the character of crusher run. If most or all of the fragments are as small as fine sand grains and no recementation has taken place, crushed rock below the water table exhibits the properties of a water-bearing sand.

Squeezing rock slowly advances into the tunnel without perceptible volume increase. A prerequisite for squeeze is a high percentage of microscopic and sub-microscopic particles of micaceous minerals or clay minerals with a low swelling capacity.

Swelling rock advances into the tunnel chiefly on account of expansion. The capacity to

swell seems to be limited to those rocks that contain clay minerals such as montmorillonite, with a high swelling capacity.

3 Classifications Involving Stand-up Time

Lauffer (1958) proposed that the stand-up time for an unsupported span is related to the quality of the rock mass in which the span is excavated. In a tunnel, the unsupported span is defined as the span of the tunnel or the distance between the face and the nearest support, if this is greater than the tunnel span. Lauffer's original classification has since been modified by a number of authors, notably Pacher et al (1974), and now forms part of the general tunnelling approach known as the New Austrian Tunnelling Method.

The significance of the stand-up time concept is that an increase in the span of the tunnel leads to a significant reduction in the time available for the installation of support. For example, a small pilot tunnel may be successfully constructed with minimal support, while a larger span tunnel in the same rock mass may not be stable without the immediate installation of substantial support.

The New Austrian Tunnelling Method includes a number of techniques for safe tunnelling in rock conditions in which the stand-up time is limited before failure occurs. These techniques include the use of smaller headings and benching or the use of multiple drifts to form a reinforced ring inside which the bulk of the tunnel can be excavated. These techniques are applicable in soft rocks such as shales, phyllites and mudstones in which the squeezing and swelling problems, described by Terzaghi, are likely to occur. The techniques are also applicable when tunnelling in excessively broken rock, but great care should be taken in attempting to apply these techniques to excavations in hard rocks in which different failure mechanisms occur.

In designing support for hard rock excavations it is prudent to assume that the stability of the rock mass surrounding the excavation is not time-dependent. Hence, if a structurally defined wedge is exposed in the roof of an excavation, it will fall as soon as the rock supporting it is removed. This can occur at the time of the blast or during the subsequent scaling operation. If it is required to keep such a wedge in place, or to enhance the margin of safety, it is essential that the support be installed as early as possible, preferably before the rock supporting the full wedge is removed. On the other hand, in a highly stressed rock, failure will generally be induced by some change in the stress field surrounding the excavation. The failure may occur gradually and manifest itself as spalling or slabbing or it may occur suddenly in the form of a rock burst. In either case, the support design must take into account the change in the stress field rather than the "stand-up" time of the excavation.

4 Rock Quality Designation Index (*RQD*)

The Rock Quality Designation index (*RQD*) was developed by Deere to provide a quantitative estimate of rock mass quality from drill core logs. *RQD* is defined as the

percentage of intact core pieces longer than 100 mm in the total length of core. The core should be at least NW size (54.7 mm in diameter) and should be drilled with a double-tube core barrel. The correct procedures for measurement of the length of core pieces and the calculation of *RQD* are summarised in Figure 10.1.

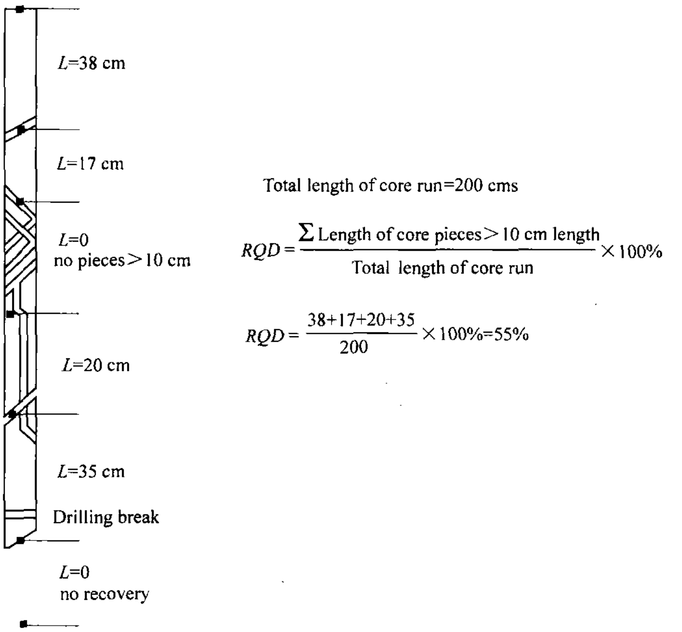


Figure 10.1 Procedure for measurement and calculation of *RQD* (After Deere, 1989)

Palmström (1982) suggested that, when no core is available but discontinuity traces are visible in surface exposures or exploration adits, the *RQD* may be estimated from the number of discontinuities per unit volume. The suggested relationship for clay-free rock masses is

$$RQD = 115 - 3.3\,Jv \tag{10.1}$$

where, Jv is the sum of the number of joints per unit length for all joint (discontinuity) sets known as the volumetric joint count.

RQD is a directionally dependent parameter and its value may change significantly, depending upon the borehole orientation. The use of the volumetric joint count can be quite useful in reducing this directional dependence.

RQD is intended to represent the rock mass quality in situ. When using diamond drill core, care must be taken to ensure that fractures, which have been caused by handling or the drilling process, are identified and ignored when determining the value of *RQD*. When using Palmström's relationship for exposure mapping, blast induced fractures should not be included when estimating Jv.

Deere's *RQD* has been widely used, particularly in North America, for the past 25 years. Cording and Deere (1972), Merritt (1972) and Deere and Deere (1988) have attempted to relate *RQD* to Terzaghi's rock load factors and to rockbolt requirements in tunnels. In the context of this discussion, the most important use of *RQD* is as a component of the *RMR*.

New Words and Expressions

1.preliminary [pri'liminəri] *a.* 初始的，初步的，预先的
2.hydrologic [hai'drɔlədʒik] *a.* 水文(学)的
3.check-list (核对用)清单
4.spectrum ['spektrəm] *n.* 领域，范围，系列
5.conjunction [kən'dʒʌŋkʃən] *n.* 连接
6.empirical [em'pirikəl] *a.* 经验的，实验的
7.pertinent ['pə:tinənt] *a.* 中肯的，贴切的
8.concise [kən'sais] *a.* 简明的，扼要的
9.spall [spɔ:l] *n.* 剥落，散裂
10.pop [pɔp] *vt.* 爆裂
11.spontaneous [spɔn'teinjəs, -niəs] *a.* 自发的，自然的
12.seamy ['si:mi] *a.* 有缝的，有疤痕的
13.cementation [ˌsi:men'teiʃən] *n.*胶结
14.prerequisite ['pri:'rekwizit] *n.* 先决条件
15.micaceous [mai'keiʃəs] *a.* 云母状的
16.montmorillonite [ˌmɔntəmə'riləˌnait] *n.* 蒙脱石
17.substantial [səb'stænʃəl] *a.* 坚固的，坚实的
18.heading ['hediŋ] *n.* 掌子面
19.bench [bentʃ] *n.* 台阶
20.shale [ʃeil] *n.* 页岩
21.phyllite ['filait] *n.* 千枚岩
22.mudstone ['mʌdstəun] *n.* 泥岩
23.prudent ['pru:dənt] *a.* 谨慎的，慎重的
24.scaling ['skeiliŋ] *n.* 按比例
25.slab [slæb] *v.* 切片，把……分成厚片
26.map [mæp] *v.* 测绘，绘制
27.formalise ['fɔ:məlaiz] *vt.* 使定形
28.detachment [di'tætʃmənt] *n.* 分离

岩体分类

在工程项目可行性和前期设计阶段，当岩体本身和它的应力状态及其水力特征信息很少时，利用岩体分类方案非常有益。采用的分类方案要简明扼要，使所有可考虑的信息保证在分类表中。从另一方面考虑，一种或多种岩体分类可用于构建岩体结构和特性的画面，从而来提供支护要求的初步评价和岩体强度及变形特征的评估。

理解使用岩体分类方案不能替代一些更加详细的设计过程，这一点很重要。然而，利用这些设计程序需要了解现场应力、岩体性质和计划开挖顺序等相对较详细的信息，但在项目早期阶段，这些有价值的资料可能并不多。这些有价值的信息更多时，岩体分类方案就会更进一步细化，并可用于现场专门分析。

一、工程岩体分类

岩体分类方案已经发展了100多年，自从Ritter(1879)试图定形隧洞设计用经验方法，特别是在确定支护要求时这一工作就开始了。当分类项目对原有使用是合适的，如在其后变化了的历史情况范围内使用，即把该分类用于其他工程问题时必须非常小心。

本章提出一些重要分类系统的总结，尽管每一分类都尽力从原文中引入所有相关资料，仍还有很多注释和说明未包括进去。感兴趣的读者应当下点工夫阅读引用参考文献，以全面了解每个系统的使用、优点和局限性。

从土木工程历史情况考虑，Bieniawski 和 Barton 等提出多参数岩体分类，在分类中

包括了所有岩体工程地质组分。在地下硬岩开挖中，尤其深部岩体风化和水的影响通常并不显著并可以忽略。不同的分类系统强调不同的参数，因此推荐在工程早期阶段在任何场址至少采用两种方法。

二、Terzaghi 岩体分类

隧洞支护设计使用岩体分类的最早文献是 Terzaghi(1946)的文章，其中由钢架承担的岩石荷载以岩体分类为依据加以估算。当利用 Terzaghi 分类讨论支护设计并不合适时，从他的原文出发检查所包括的岩体描述是有意义的，原因是他删除了控制岩体特征的一些论述，对自重应力问题更是这样。在这些描述中所包括的简洁清晰定义和实际评价是工程地质信息的良好实例，这些信息对工程设计非常有用。

Terzaghi 描述：

完整岩石既无节理又无破裂。因此，如果它破裂，就是完整岩体的破坏。由于爆破对岩石的损伤，在爆破几小时或几天后洞顶可能出现剥落，说明剥落条件是已知的。对坚硬完整岩石来说，在爆破条件下会有瞬时的、猛烈的岩片从边墙和洞顶剥落下来。

成层岩体具成层性，当层与层之间分开时，抗阻力很小。横节理可能会使岩层强度变坏。这种岩石沿层面劈开很常见。

中度节理岩体，具有节理和微细裂纹，但节理之间块体强度增高以至于胶结紧密，洞室侧墙不需侧向支撑。在这类岩石中，剥蚀和岩爆都可能会遇到。

块状和有裂缝岩体包含化学上是完整的或近于完整的岩石碎片，这些碎片全部被分开或相互胶结不完好。在这种岩体中，直墙需要侧向支承。

碎片岩未受化学扰动具有轧碎的特征。如果大部分或几乎所有碎片像细砂颗粒一样小，之间不存在胶结，水位线以下这种破碎岩石具有含水砂的特征。

受挤压作用岩石缓慢向洞内变形，隧洞开挖体积没有明显增加。如发生挤压必要条件，具有低膨胀性的云母矿物或黏土矿物显微颗粒和次显微颗粒百分含量要高。

崩膨岩主要由于膨胀作用使岩体向隧道内移动。膨胀能力受岩石含黏土矿物多少控制，如含高膨胀性蒙脱石的岩石。

三、隧洞自稳时间分类

Lauffer 提出无支护跨度自稳时间与开挖洞室岩体质量有关。在隧道内，无支护跨度定义为隧道的跨度或工作面和最近支护间的距离，并认为该距离大于隧道的跨度。Lauffer 的初始分类经过很多学者的修订尤其是 Pacher 等(1974)的修订，现在成了隧洞加固的一部分，叫新奥地利施工法(NATM)。

自稳时间概念的重要性表现在隧道跨度增加导致临时支护时间会减少。例如，对于小的导洞用少量支护就可建成，然而同样岩体中大跨度隧洞开挖后没有立即根本性的支护可能是不稳的。

对岩石来说，为了隧洞安全，新奥法(NATM)包括多种技术，其中在洞室破坏前隧洞自稳时间要加以控制。这些技术包括采用小的导洞、台阶开挖或使用分层开挖来安装预应力环，对环之间的隧洞岩体进行开挖。这些技术主要应用于软岩地区、如页岩、千

枚岩和泥岩等，其中由 Terzaghi 所描述的膨胀和挤压问题可能会发生。这些技术也用于非常破碎岩体，但是在坚硬岩体中采取这些技术应该非常小心，因为这些地区岩石破坏机理不同。

在硬岩开挖支护设计中，假定开挖边界岩体稳定性与时间无关这一点要谨慎对待。因此，当结构上定义的楔体出露于洞室的顶部时，一旦支护楔体岩石移动，它就会塌落。这种现象发生在爆破时或随后的扩挖期间。如果让楔体保持不动，或加强安全性，尽早安装支护很必要，最好在支护前把楔体全部清除。另外，受高地应力岩体，破坏一般是由于开挖导致洞室周围应力场环境改变而产生。这种破坏可能是逐渐地或表现为自行剥落、片帮或以岩爆的形式突然发生。在任何情况下，支护设计必须考虑应力场的改变而不是开挖的自稳时间。

四、岩石质量指标(*RQD*)

岩石质量指标(*RQD*)由 Deere 提出，利用岩心记录对岩体质量提供一种数值评价方法。*RQD* 定义为大于 100 mm 完整岩心占岩心总长度的百分数。岩心应为标准尺寸(直径 54.7 mm)并用双层岩心管钻进。测量岩心长度和 *RQD* 计算方法汇总于图 10.1。

Palmström(1982)提出，没有岩心资料但在地表露头和导洞内能见到一些不连续节理，*RQD* 可根据单位体积内不连续节理来估计。对于不含黏土的岩体换算关系为

$$RQD=115-3.3Jv \tag{10.1}$$

式中：*Jv* 为单位长度上所有节理(不连续)总条数，又称体积节理数。

RQD 是一个直接独立参数，其值变化明显，和钻孔方向有关。利用体积节理数可有效地减少方向依赖性。

RQD 指标能较好地反映现场的岩体质量。当采用金钢石钻头取心时，务必小心，以确保由于手工或钻进过程产生的破碎情况被辨识出来，当计算 *RQD* 值，该破碎不计。当利用 Palmotröms 关系测绘露头时，估计的 *Jv* 不包括因爆破产生的破裂情况。

在过去的 25 年里，Deere 的 *RQD* 得以广泛应用，尤其是北美地区。Cording 等试图建立 Terzaghi 岩石加载系数与 *RQD* 的关系以及隧洞对岩石锚杆可否需要的关系。从讨论的内容看，*RQD* 是 *RMR*(综合特征值)的一个重要组分。

Reading Material

Geomechanics Classification of Rock Mass

Bieniawski (1976) published the details of a rock mass classification called the Geomechanics Classification or the Rock Mass Rating (*RMR*) system. Over the years, this system has been successively refined as more case records have been examined and the reader should be aware that Bieniawski has made significant changes in the ratings assigned to different parameters. The discussion which follows is based upon the 1989 version of the classification (Bieniawski, 1989).The following six parameters are used to classify a rock

mass using the *RMR* system:

(1) Uniaxial compressive strength of rock material.

(2) Rock Quality Designation (*RQD*).

(3) Spacing of discontinuities.

(4) Condition of discontinuities.

(5) Groundwater conditions.

(6) Orientation of discontinuities.

In applying this classification system, the rock mass is divided into a number of structural regions and each region is classified separately. The boundaries of the structural regions usually coincide with a major structural feature such as a fault or with a change in rock type. In some cases, significant changes in discontinuity spacing or characteristics, within the same rock type, may necessitate the division of the rock mass into a number of small structural regions.

The Rock Mass Rating system is presented in Table 10.1, giving the ratings for each of the six parameters listed above. These ratings are summed to give a value of *RMR*. The following example illustrates the use of these tables to arrive at a *RMR* value.

A tunnel is to be driven through a slightly weathered granite with a dominant joint set dipping at 60° against the direction of the drive. Index testing and logging of diamond drilled core give typical Point-load strength index values of 8 MPa and average *RQD* values of 70%. The slightly rough and slightly weathered joints with a separation of < 1 mm, are spaced at 300 mm. Tunnelling conditions are anticipated to be wet.

Table 10.1 The *RMR* value

	Item	Value	Rating
A.1	Point-load index	8 MPa	12
A.2	*RQD*	70%	13
A.3	Spacing of discontinuities	300 mm	10
A.4	Condition of discontinuities	Note 1	22
A.5	Groundwater	Wet	7
B	Adjustment for joint orientation	Note 2	–5
	Total		59

Note 1. For slightly rough and altered discontinuity surfaces with a separation of < 1 mm, Table10.1.A.4 gives a rating of 22. When more detailed information is available, Table 10.1.A.4 can be used to obtain a more refined rating. Hence, in this case, the rating is the sum of:4 (1 ~ 3 m discontinuity length), 4 (separation 0.1~1.0 mm), 3 (slightly rough), 6 (no infilling) and 5 (slightly weathered) = 22.

Note 2. Table 10.1 gives a description of "Fair" for the conditions assumed where the tunnel is to be driven against the dip of a set of joints dipping at 60°. Using this description for "Tunnels and Mines" in Table 10.1.B gives an adjustment rating of –5.

Bieniawski (1989) published a set of guidelines for the selection of support in tunnels in rock for which the value of *RMR* has been determined. These guidelines are reproduced in Table 10.2. Note that these guidelines have been published for a 10 m span horseshoe shaped tunnel, constructed using drill and blast methods, in a rock mass subjected to a vertical stress < 25 MPa (equivalent to a depth below surface of <900 m).

Table 10.2 Guidelines for excavation and support of 10 m span rock tunnels in accordance with the *RMR* system (After Bieniawski, 1989)

Rock mass class	Excavation	Rock bolts (20 mm diameter, fully grouted)	Shotcrete	Steel sets
Ⅰ — Very good rock *RMR*: 81~100	Full face, 3 m advance	Generally no support required except spot bolting		
Ⅱ — Good rock *RMR*: 61~80	Full face, 1~1.5 m advance. Complete support 20 m from face	Locally, bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh	50 mm in crown where required	None
Ⅲ — Fair rock *RMR*: 41~60	Top heading and bench 1.5~3 m advance in top heading. Commence support after each blast. Complete support 10 m from face	Systematic bolts 4 m long, spaced 1.5~2 m in crown and walls with wire mesh in crown	50~100 mm in crown and 30 mm in sides	None
Ⅳ — Poor rock *RMR*: 21~40	Top heading and bench 1.0~1.5 m advance in top heading. Install support concurrently with excavation, 10 m from face	Systematic bolts 4~5 m long, spaced 1~1.5 m in crown and walls with wire mesh	100~150 mm in crown and 100 mm in sides	Light to medium ribs spaced 1.5 m where required
Ⅴ —Very poor rock *RMR*: < 20	Multiple drifts 0.5~1.5 m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting	Systematic bolts 5~6 m long, spaced 1~1.5 m in crown and walls with wire mesh. Bolt invert	150~200 mm in crown, 150 mm in sides, and 50 mm on face	Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close invert

For the case considered earlier, with *RMR* = 59, Table 10.2 suggests that a tunnel could be excavated by top heading and bench, with a 1.5 to 3 m advance in the top heading. Support should be installed after each blast and the support should be placed at a maximum distance of 10 m from the face. Systematic rock bolting, using 4 m long, 20 mm diameter fully grouted bolts spaced at 1.5 to 2 m in the crown and walls, is recommended. Wire mesh, with 50 to 100 mm of shotcrete for the crown and 30 mm of shotcrete for the walls, is recommended.

The value of *RMR* of 59 indicates that the rock mass is on the boundary between the

"Fair rock" and "Good rock" categories. In the initial stages of design and construction, it is advisable to utilise the support suggested for fair rock. If the construction is progressing well with no stability problems, and the support is performing very well, then it should be possible to gradually reduce the support requirements to those indicated for a good rock mass. In addition, if the excavation is required to be stable for a short amount of time, then it is advisable to try the less expensive and extensive support suggested for good rock. However, if the rock mass surrounding the excavation is expected to undergo large mining induced stress changes, then more substantial support appropriate for fair rock should be installed. This example indicates that a great deal of judgement is needed in the application of rock mass classification to support design.

It should be noted that Table 10.2 has not had a major revision since 1973. In many mining and civil engineering applications, steel fibre reinforced shotcrete may be considered in place of wire mesh and shotcrete.

New Words and Expressions

1.geomechanics [ˌdʒi(:)əumiˈkæniks] *n.* 地质力学
2.rate [reit] *vt.* 等级，权重
3.refine [riˈfain] *vt.* 精制，精炼，提纯
4.uniaxial [ˈju:niˈæksiəl] *a.* 单轴的
5.coincide [ˌkəuinˈsaid] *vi.*(与……)相同；与……一致(with)
6.necessitate [niˈsesiteit] *v.* 使成为必要
7.dip [dip] *v.* 倾斜
8.log [lɔg] *v.* 记录
9.discontinuity [ˈdisˌkɔntiˈnju(:) iti] *n.* 不连续面
10.guideline [ˈgaidˌlain] *n.* 方针，指南
11.horseshoe [ˈhɔ:ʃʃu:, ˈhɔ:sʃu:] *n.* 马蹄状
12.heading [ˈhediŋ] *n.* 水平巷道
13.bench [bentʃ] *n.* 台阶
14.grout [graut] *vt.* 灌浆
15.wire mesh 铁丝网
16.shotcrete [ʃɔtkri:t] *n.* 喷混凝土

阅读材料

岩体的地质力学分类

Bieniawski(1976)发表了详细的岩体分类方法，即地质力学分类或岩体质量划分系统(即综合特征值 *RMR*)。在随后的很多年里，由于更多实例应用，这个系统得以成功的修改完善，读者应认识到 Bieniawski 已在不同参数权值上做了很大调整。下面所讨论的是基于 1989 版分类系统。使用 *RMR* 分类系统要涉及下面 6 个参数：

(1)岩石材料单轴抗压强度。
(2)岩石质量指标(*RQD*)。
(3)节理不连续间距。
(4)节理不连续状态。

(5)地下水情况。

(6)不连续面方位。

在使用该分类系统时，岩体被分成许多结构单元，每个单元再单独分类。结构单元边界通常和主要结构特征面一致如断层或岩石类型。在一些情况下，在同一岩类中，由于不连续面间距或特征的显著变化，很有必要把该岩体分成次一级的结构单元。

表 10.1 给出了岩体 *RMR* 体系及 6 个参数的权值，这些权值总和即为 *RMR* 值。下面举例说明利用该表得到的 *RMR* 值。

一条隧道穿越微风化的花岗岩体，主要节理倾向方位与开挖方向成 60° 夹角。由标准试验和金刚钻进岩心典型点荷载强度为 8 MPa，平均 *RQD* 值为 70%。稍粗糙，微风化节理面的张开度小于 1 mm，间距 300 mm；开挖条件预测为潮湿。

Bieniawski(1989)出版了一套由 *RMR* 值对岩石隧道支护方式选取的指南。表 10.2 给出了这些指南的内容。注意这些指南针对 10 m 跨度马蹄形隧道，采用钻爆法，岩体受的铅直应力小于 25 MPa(等同于地表下 900 m 内)。

对于较早一个例子 *RMR*=59，表 10.2 建议利用上导洞和台阶式开挖，上导洞超前 1.5~3 m。每次爆破后立即安装支护，安装的支护距掌子面最大距离为 10 m。顶拱和边墙采用系统岩石锚杆，长 4 m，直径 20 mm，间距 1.5~2.0 m 全孔注浆。挂钢丝网时在顶拱喷 50~100 mm 厚的混凝土，在边墙喷 30 mm 厚的混凝土。

RMR 值为 59 说明岩体介于“一般”和“好”之间。在设计和施工的前期，对一般性岩体采取所建议的支护措施是合适的。若施工过程顺利，无稳定问题，且支护很好地发挥作用，对于好岩体支护必要性逐渐减少是可能的。此外，如果要求岩体开挖后短时间内达到稳定，对于好岩石可能设法减少成本支护是可行的。然而，如果开挖岩体周围有大的洞室，岩体应力会发生变化，对质量一般的岩体应采取更加坚固的支护措施。这个实例说明把围岩分类用于支护设计，做详细调查是需要的。

应当注意，自 1973 年来，表 10.2 还没经过大的修订。在许多采矿业、土木工程应用中，可考虑用钢纤维喷混凝土替代钢丝网喷混凝土。

Unit 11

Text

Deformation of Rock Slopes

In a slope in which the rock is jointed but where there are no significant discontinuities dipping out of the slope which could cause sliding, deformation and failure of the slope is controlled by a complex process of block rotation, tilting and sliding. In an extreme case, where the rock mass consists of near vertical joints separating columns of massive rock, toppling movement and failure may occur.

Figure11.1 is a section through part of the power tunnel for the Wahleach hydroelectric project in British Columbia, Canada. A break in the steel lining in this power tunnel occurred in January 1989 and it is thought this break was caused by a slow down-slope gravitational movement caused by block rotations within a near-surface zone of loosened jointed rock.

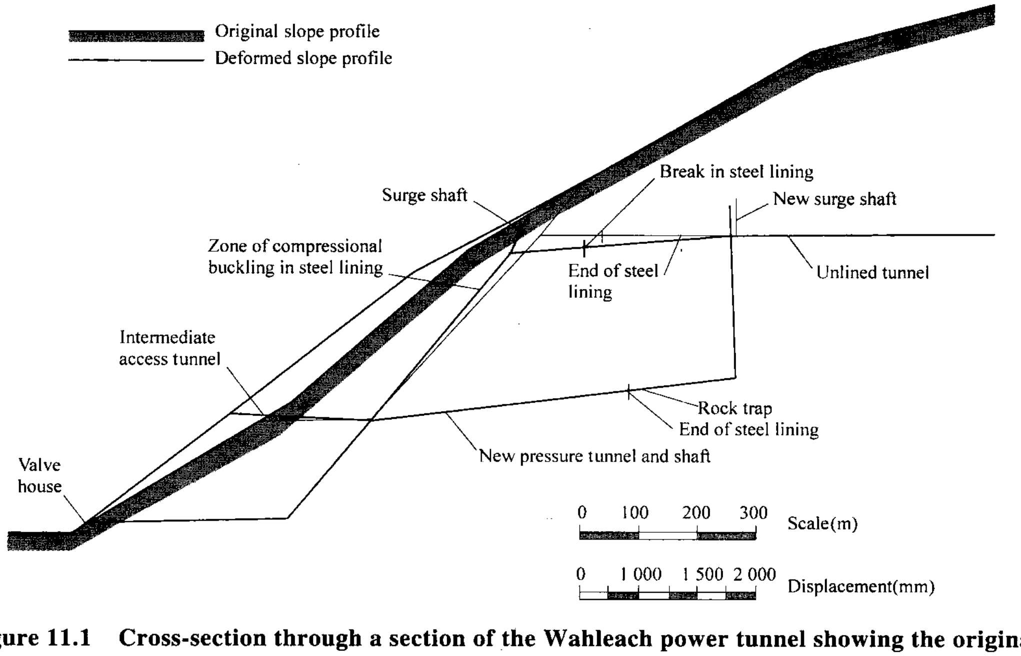


Figure 11.1 Cross-section through a section of the Wahleach power tunnel showing the original tunnel alignment and the location of the replacement conduit

The deformed shape of the hillside is shown (exaggerated) and the replacement pressure tunnel was located in a zone of small deformations

The Wahleach project is located 120 km east of Vancouver and power is generated from 620 m of head between Wahleach Lake and a surface powerhouse located adjacent to the Fraser River. Water flows through a 3 500 m long three metre diameter unlined upper tunnel, a rock trap, a 600 m two metre diameter concrete encased steel lined shaft inclined at 48° to the horizontal, a 300 m long lower tunnel and a 485 m long surface penstock to the powerhouse.

The tunnels were excavated mainly in granodiorite which varies from highly fractured and moderately weathered in the upper portions of the slope to moderately fractured and fresh in both the lower portions of the slope and below the highly fractured mass. Two main joint sets occur in the rock mass, one set striking parallel to the slope and the other perpendicular to it. Both dip very steeply. Average joint spacings range from 0.5 to 1 m. A few joints occur sub-parallel to the ground surface and these joints are most welldeveloped in the ground surface adjacent to the inclined shaft. Thorough investigations failed to reveal any significant shear zones or faults oriented in a direction conducive to sliding.

The toe of the slope is buried beneath colluvial and fan deposits from two creeks which have incised the Fraser Valley slope to form the prominence in which the inclined shaft was excavated. This prominence is crossed by several linear troughs which trend along the ground surface contours and are evidence of previous down-slope movement of the prominence. Mature trees growing in these troughs indicate a history of movement of at least several hundred years.

The water conduit operated without incident between the initial filling in 1952 and May 1981 when leakage was first noted from the upper access adit located near the intersection of the inclined shaft and the upper tunnel (see Fig. 11.1). This leakage stopped when two drain pipes embedded in the concrete backfill beneath the steel lining were plugged at their upstream ends. Large holes had been eroded in these drainage pipes where they were not encased in concrete and it was concluded that this corrosion was responsible for the leakage. This conclusion appeared to be valid until 25 January, 1989 when a much larger water flow occurred.

Investigations in the dewatered tunnel revealed a 150 mm wide circumferential tension crack in the steel lining of the upper tunnel, about 55 m from its intersection with the inclined shaft. In addition, eight compressional buckle zones were found in the upper portion of the inclined shaft. Subsequent investigations revealed that approximately 20 million cubic metres of rock are involved in down-slope creep which, during 1989 ~ 1990, amounted to several centimetres per year and which appears to be ongoing. This downslope creep appears to be related to a process of block rotation rather than to any deep seated sliding as was the case at both the Downie Slide and Dutchman's Ridge. While discrete element models may give some indication of the overall mechanics of this type of slope deformation, there is no way in which a factor of safety, equivalent to that for sliding failure, can be calculated. Consequently, in deciding upon the remedial measures to be implemented, other factors have to be taken into

consideration. After thorough study by the BC Hydro and their consultants, it was decided to construct a replacement conduit consisting of an unlined shaft and tunnel section and a steel lined section where the rock cover is insufficient to contain the internal pressure in the tunnel. This replacement conduit, illustrated in Figure 11.1, will remove the steel lined portions of the system from zones in which large displacements are likely to occur in the future. This in turn will minimise the risk of a rupture of the steel lining which would inject high pressure water into the slope. It was agreed that such high pressure water leakage could be a cause for instability of the overall slope. Further studies are being undertaken to determine whether additional drainage is required in order to provide further safeguards.

Careful measurements of the displacements in the inclined shaft, the length of the steel lining can as compared with the original specified lengths and the opening of the tensile crack in the upper portion of the steel lined tunnel, provided an overall picture of the displacements in the rock mass. These observed displacements were compared with displacement patterns computed by means of a number of numerical studies using both continuum and discrete element models and the results of these studies were used in deciding upon the location of the replacement conduit.

In addition to the construction of this replacement conduit to re-route the water away from the upper and potentially unstable part of the slope, a comprehensive displacement and water pressure monitoring system has been installed and is being monitored by BC Hydro.

New Words and Expressions

1.deformation [di:fɔ:'meiʃən] *n.* 变形
2.slope [sləup] *n.* 边坡，斜坡
3.joint ['dʒɔint] *n.* 节理
4.topple ['tɔpl] *v.* 倾覆
5.lining ['lainiŋ] *n.* 衬砌
6.trap [træp] *n.* 槽，U 型井
7.penstock ['penstɔk] *n.* 压力钢管，进水管
8.excavate ['ekskəveit] *v.* 挖掘，开挖
9.granodiorite [ˌgrænəu'daiəˌrait] *n.* 花岗闪长岩
10.strike [straik] *n.* 走向
11.dip ['dip] *n.* 倾向
12. sub-parallel ['sʌb'pærəlel] *n.* 略平行
13. colluvial [kə'lu:viəl] *a.* 崩积的
14. incise [in'saiz] *v.* 切割，蚀刻
15. prominence ['prɔminəns] *n.* 突起
16. adit ['ædit] *n.* 坑道，平洞，入口
17.dewater [di:'wɔ:tə] *v.* 排水，抽水
18. buckle ['bʌkl] *n.* 纵弯曲
19. shaft [ʃɑ:ft] *n.* 竖井，矿井
20. monitor ['mɔnitə] *n.* 监测
21. discrete element method 离散单元法

岩质边坡的变形

在边坡体内，如果岩体存在节理，但没有倾向坡外的引起边坡滑动的重大不连续，边坡的变形和破坏是由一系列复杂的岩块转动、倾倒和滑动过程所控制。在极端情况下，岩体由几乎垂直的节理分割成块柱状岩块时，可能会发生倾倒移动和破坏。

图 11.1 是加拿大 BC(British Columbia)省 Wahleach 水电工程发电洞的一个剖面。1989 年 1 月发电洞钢衬产生了一裂纹，其原因是由于近地表的松散节理岩石发生了转动，而使斜坡在重力作用下缓慢滑移造成的。

Wahleach 工程位于 Vancouver 以东 120 km，发电是由 Wahleach 湖和与 Fraser 河相邻的地面发电站之间 620 m 的水头差产生的。在上游水流通过长 3 500 m、直径 3 m 的非衬砌隧洞，其下通过一条岩石明渠，长 600 m、直径 2 m 与水平方向呈 48°夹角的混凝土外壳钢衬砌斜井，接着是一条长 300 m 下游隧洞和一条长 485 m 地表压力钢管输送到发电厂房。

发电洞在花岗闪长岩体内开挖，在边坡上部岩石破碎、中等风化，在边坡下部和严重破碎的岩体之间为中等破碎和新鲜状态。岩体中存在两组节理，一组走向平行于边坡，另一组则垂直于边坡。两组倾角较陡。平均节理间距 0.5 ~ 1.0 m。另有少部分节理略平行于地表面，在地表靠近斜井发育。通过勘察，并没发现有利于滑动方向上的任何大型的剪切带和断层。

边坡的坡脚埋藏在崩积物和两条小溪形成的扇形冲积物下，小溪切割 Fraser 山谷斜坡，并形成了一个山嘴，斜井布置在其中。山嘴被几条线状沟槽切割，且沿地面等高线分布，说明这个山嘴曾经向坡下移动过。生长在沟槽中的大树表明这些移动至少已有几百年。

从 1952 年蓄水到 1981 年 5 月前，输水管运行正常。1981 年 5 月第一次发现在上游支洞入口有渗水即在斜井和上游隧洞交叉处附近(见图 11.1)。当把两个在钢衬之下埋置在混凝土填料的排水管上游段堵塞，渗漏就停止了。没有混凝土包裹的排水管形成大的侵蚀洞，因此得到的结论是侵蚀是形成渗漏的原因。直到 1989 年 1 月 25 日才认为这个结论是对的，确有大量渗水流出。

对排水洞调查发现，在距斜井交叉处 55 m，上游隧洞钢衬砌中有宽 150 mm 的环形张裂缝。另外，在斜井上部有 8 条被挤压的弯曲带。随后调查显示，在 1989 ~ 1990 年，大约 2 000 万 m^3 岩石向斜坡下蠕动，达到每年有几厘米，现在仍在蠕动。这种向坡脚的蠕动和岩石转动过程有关，而不同于 Downie 滑坡和 Duthman 山脊那样的深层滑动。离散单元模型可以给出这种边坡变形的总体力学特征，但是对于滑动破坏时安全系数无法进行计算。于是采用修正方法加以弥补，即把其他因素考虑进去。经过 BC 省水电公司和他们咨询师的精心研究，决定修建一个替代输水管道，包括非衬砌斜井、隧洞段和钢衬砌段组成，因为钢衬砌段部分上覆岩体不能支撑隧洞内水压力。图 11.1 说明用这条代替输水管道应把这一系统的钢衬砌部分移走，从未来考虑怕有大的位移发生。把钢衬砌破坏风险降到最低，原因是它破坏会有高压水注入边坡。大家一致认为，高压水渗入斜坡可导致整个边坡的不稳定。为保证未来的安全，正在开展进一步研究来确定是否要设置排水系统。

仔细测量斜井的位移，把钢衬部分的长度与原长度和钢衬隧洞上部裂缝张开宽度做比较，就可给出岩体位移总图。把这些观测到的位移与利用连续单元和离散单元模拟研究计算的位移相比较，利用这些研究结果就可以确定替代输水管道的位置。

除了修建这条替代隧道，使水流不通过边坡的上部和潜在不稳定段，BC 省水电公司还实施了系统综合性的位移和水压力监测。

Reading Material

Landslides

Landslide is the downslope movement of rock, sediment, and soil under the influence of gravity without the aid of other agents of erosion such as flowing water, wind, or ice. Landslides range from rapid, catastrophic slides in which large masses of debris are transported off a slope within a matter of seconds or minutes to the imperceptible slow creep of individual particles down a gradual slope. These types of movements may be triggered by the vibrations from earthquakes or the mechanical pushing or heaving of particles downslope, or they may occur spontaneously if the gravitational forces exceed the forces holding the material to the slope. Five basic types of landslides are defined, based on the type of movement involved: falls, slides, slumps, flows, and creep.

Falls are created by the free fall of rocks or coherent masses of sediment from steep cliffs. The coarse debris that breaks loose from the cliff tumbles over the slope and accumulates to form talus or scree deposits at the base of the slope. Slides are slope failures in which a large mass of rock and debris slips downslope along a zone of weakness, usually a bedding plane or structural surface (a fault or joint). The d́ebris removed from the slope may come to rest anywhere from a meter to a kilometer downslope. A scar is left on the slope delineating the area in which the debris originated. Slumps are generated when a block of sediment breaks loose from its bed and slides downward and outward as a coherent unit along a curved failure plane. As the failed block rotates from its original position, it produces a scarp or concave scar on the slope. Sliding and slumping may occur suddenly in one great landslide or in a series of small displacements that take place over months or years. Flows are created by the downslope movement of water-saturated debris. The material being transported may remain semi-coherent or may become jumbled and mixed. These soggy masses may move rapidly downslope in a few minutes (mudflows and debris flows on alluvial fans) or at a rate of only a few centimeters or meters per hour or day for a short period (solifluction and gelifraction); creep is the extremely slow, almost undetectable downslope movement of soil particles in the upper meter of the soil caused by a variety of mechanisms. Particles may simply roll down the hillside, burrowing animals may push sediment down the slope, or particles may slowly move or freezing and thawing.

The term colluvium is used to describe sediments that are eroded, trans-ported, and deposited on and at the base of slopes by gravity. Colluvial deposits range from accumulations of coarse rock fragments to clay-size particles but are commonly a poorly sorted mixture of both coarse and fine-grained particles.

New Words and Expressions

1.particle ['pɑ:tikl] *n.* 颗粒，微粒
2.heave [hi:v] *v.* 水平移动
3.downslope *a.* 下坡的
4.break loose 塌岩堆
5.talus ['teiləs] *n.* 崩塌岩堆
6.scarp [skɑ:p] *n.* 崖，陡坡
7.concave [kɔn'keiv] *a.* 凹形的
8.delineate [di'linieit] *vt.* 刻划，画轮廓，描写
9.jumble ['dʒʌmbl] *v.* 混合，掺杂
10.soggy ['sɔgi] *a.* 潮湿的，浸水的
11.solifluction [ˌsɔli'flʌkʃən] *n.* 泥流
12.gelifraction [ˌdʒeli'frækʃən] *n.* 冻融泥流

阅读材料

滑　坡

滑坡是岩石、沉积物、土体在重力作用下沿斜面向下的运动，它不包括其他因素如冲刷、侵蚀、风、冰的作用等。滑坡包括一些大体积碎屑物在几秒、几分钟内迅速、灾难性地脱离坡体到一些细颗粒在边坡上的不可察觉的缓慢蠕动。这些类型的运动，可能由地震的震动或机械力的冲撞或颗粒受到向坡下的牵引而引发，或者重力超过边坡的自稳定力而自发引起滑动。根据滑坡运动形式定义为 5 个基本类型：崩塌、滑坡、塌落、流动和蠕变。

崩塌是由陡壁上岩石或沉积物自由落体造成的。这些由陡崖跌落破坏的松散粗粒碎屑物越过斜坡并在斜坡底形成碎石堆或岩屑堆。滑坡是指大块岩石和碎屑沿软弱带，通常为岩层面或结构面(如断层或节理)滑动而破坏。从坡体上移动的岩屑可能会移动 1 m 到 1 000 m，将有刻痕留在斜坡岩石上，有刻痕的区域是碎屑原生位置。沉积物块体从原岩处发生破坏松动并作为一个整体沿弯曲破坏面向下向外滑动就形成塌落。当破坏块体从起始位置滚动时，会在斜坡上留下陡坎和凹槽。滑坡和塌落是一个大的块体突然发生运动或一系列小的移动——经过几个月乃至几年的移动。流动是指水饱和的碎屑沿边坡向下移动形成的。运动物质可能保持半黏结状或发生掺和或混合。这些饱水物质可能在几分钟内迅速滑下(如冲击扇上的泥流和碎屑流)，或在不长时段内，每小时、每天仅仅几厘米或几米的速率下滑(如泥流和冻融泥流)；蠕变极其缓慢，几乎觉察不到，由不同机理引起的土颗粒向山坡下移动。有的土颗粒只是简单地向山坡下滚动，动物挖洞穴推出土体向下移动，或者颗粒自身缓慢下移，因冻融使颗粒缓慢向下移动。

崩积物是用来描述在重力作用下被侵蚀、搬运、沉积在坡上或坡底的堆积物。崩积物由粗岩石碎屑到黏粒颗粒组成，通常可以说是一种较差的粗颗粒和粉细颗粒混合物。

Unit 12

Text

Evaluation of Long-term Remedial Measures

While the short-term threat of instability was considered to be small, the longer-term stability of the slope was considered to be unacceptable and a study was carried out to evaluate various options for stabilising the slope. It was agreed that a factor of safety of 1.5 was required to meet long term requirements.

The following alternatives were considered:

(1)Reducing the height of the slope.

(2)Reducing the angle of the slope face.

(3)Drainage of the slope.

(4)Reinforcement of the slope.

The limit equilibrium models were used for this evaluation and the results are plotted in Figure12.1.

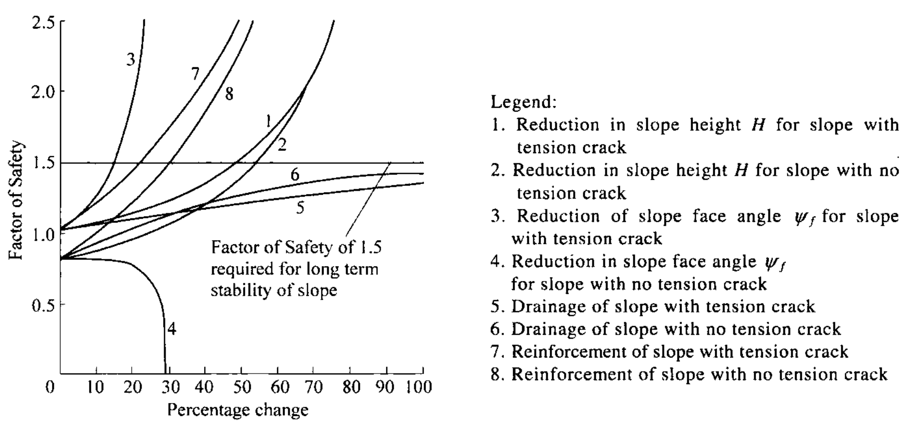


Figure 12.1 Evaluation of remedial options to increase the stability of the slope

In calculating the factors of safety shown in this figure, the shear strength was maintained constant and was defined by c =0.10 MPa and φ =35°. Similarly, an earthquake acceleration of α=0.08 g was used for all the analyses. The percentage change refers to the ratios of slope height, slope angle and water depth to the original dimensions defined.

In the case of the reinforcement options, the percentage change refers to the ratio of

anchor force T to the weight of the wedges (24.8 MN for the slope with the tension crack and 28.6 MN for the slope with no tension crack). The anchor inclination was kept constant at $\theta=\varphi=35°$. This anchor inclination gives the minimum anchor load for a dry slope and it can be determined by minimising equations with respect to θ.

The curves presented in Figure 12.1 show clearly that some remedial measures are much more effective than others and it is worth examining each of the options in turn.

Curves 1 (slope with tension crack) and 2 (slope without tension crack) show that reduction of the slope height is not an effective solution to the problem. In order to achieve the required factor of safety of 1.5, the slope height would have to be reduced by 50%. If this solution were to be adopted, it would be more practical to excavate the entire slope since most of the volume of the rock to be excavated is contained in the upper half of the slope.

Curve 3 (slope with tension crack) shows that reduction of the slope angle is a very effective remedial measure.The required factor of safety of 1.5 is achieved for a reduction of less than 25% of the slope angle. In other words, a reduction of the overall slope face angle from 50° to 37.5° would achieve the desired result. This finding is generally true and a reduction in the face angle of a slope is usually an effective remedial step. In the case of slopes under construction, using a flatter slope is always one of the prime choices for achieving greater stability.

Curve 4 (slope without tension crack) is an anomaly and demonstrates that calculations can sometimes produce nonsense. The reduction in factor of safety shown by this curve is a result of the reduction in the weight of the sliding block as the face angle is reduced. Since the water pressure on the sliding surface remains constant, the effective stress acting on the sliding surface decreases and hence the frictional component of the resisting forces decreases. When a very thin sliver of rock remains, the water pressure will float it off the slope. The problem with this analysis lies in the assumption that the block is completely impermeable and that the water remains trapped beneath the failure surface. In fact, the block would break up long before it floated and hence the water pressure acting on the failure plane would be dissipated.

Curves 5 and 6 show that drainage is not a very effective option for either of the slope models considered. In neither case is a factor of safety of 1.5 achieved. This is something of a surprise since drainage is usually one of the most effective and economical remedial measures. The reasons for the poor performance of drainage in this case is due to the combination of the geometry of the slope and the shear strength of the failure surface.

Curves 7 and 8 show that, for both slope models considered, slope reinforcement by means of rockbolts or cables can be an effective remedial measure. The anchor force required for a factor of safety of 1.5 would be about 100 ton per metre of slope length for the slope with no tension crack.

Final decision on long-term remedial works. The two most attractive options for long-term remedial works on this slope are reinforcement by means of cables or bolts or reduction of the slope face angle. The first option was finally rejected because of the high cost and because of the uncertainty about the long-term corrosion resistance of reinforcement which could be placed in the slope. This latter concern may not have been justified but, considering the very poor quality of some of the construction in Hong Kong at the time of this study, it was decided that the risk was not worth taking.

The option finally chosen was to reduce the slope face angle down to 35° by excavating the entire block resting on the failure surface and hence removing the problem entirely. Since good quality aggregate is always required in Hong Kong it was decided to work this slope face as a quarry. It took several years to organise this activity and, during this time, the water levels in the slope were monitored by means of piezometers. Although the road was closed twice during this period, no major problems occurred and the slope was finally excavated back to the failure plane.

New Words and Expressions

1.evaluation [i,vælju'eiʃən] *n.* 估价，评价
2.remedial [ri'mi:djəl] *a.* 修补的，改造的
3.reinforcement [,ri:in'fɔ:smənt] *n.* 加强
4.anchor ['æŋkə] *n.* 锚杆，绞钉
5.inclination [,inkli'neiʃən] *n.* 倾斜，偏斜
6.anomaly [ə'nɔməli] *n.* 反常，异常
7.effective stress 有效应力
8.sliver ['slivə] *n.* 薄片
9.float [fləut] *n.* 漂流，飘移
10.trap [træp] *v.* 捕获，收集，关闭，封闭
11.dissipate ['disipeit] *v.* 消散，分散，扩散
12.drainage ['dreinidʒ] *n.* 排水，排泄
13.rockbolt ['rɔk,bəult] *n.* 岩栓，岩石锚杆
14.cable ['keibl] *n.* 钢索，锚索
15.aggregate ['ægrigeit] *n.* 集料，骨料
16.quarry ['kwɔri] *n.* 采石场
17.piezometer [,paiə'zɔmitə] *n.* 压力计，测压管

长期加固措施的评价

边坡临时不稳定性危害很小，但对边坡长期稳定性这样考虑是不可接受的，对边坡稳定性而言，进行了各种评价方案。一致认为安全系数应为 1.5，可满足长期稳定要求。

从边坡稳定考虑，可采取以下加固措施：

(1)减小坡高。

(2)减小坡角。

(3)边坡排水。

(4)加固边坡。

评价中使用了极限平衡模型，结果绘于图 12.1。

图中给出了计算安全系数，抗剪强度值假设为常数，$c=0.10$ MPa，φ=35°。同样地，在所有的分析中地震加速度α=0.08 g。与最初条件相比，坡高、坡角和水位的变化相当于原来尺寸的一个百分数。

在上述加固措施中，百分比的变化代表锚固力 T 与楔形体重量(有张裂缝边坡 24.8 MN，无张裂缝边坡 28.6 MN)的比值。锚杆的倾角保持$\theta=\varphi=35^{\circ}$的常数。该锚杆倾角对于燥边坡给出了最小倾角锚固荷载，可用相关公式对θ求最小值的方法确定。

图 12.1 所示曲线清楚地表明，一些治理措施与其他方法相比明显更为有效，依次检查每种措施是值得的。

曲线 1(具有张裂缝的边坡)和曲线 2(无张裂缝的边坡)表明，减小坡高对本问题并不是一个有效方案。为了达到所要求的安全系数值 1.5，坡高要减少 50%。如果采用这个方案，那意味着对整个边坡开挖更为切合实际，因为大部分需要开挖的岩体位于边坡的上半部分。

曲线 3(具有张裂缝的边坡)表明，减小坡角是一个非常有效的治理措施。当把坡角减小 25%，安全系数就可达到 1.5 的要求。换句话说，将总体坡角从 50°减至 37.5°，就能达到想要的结果。总体而言，这个结果是正确的，减小坡角通常是有效的治理步骤。对于正在施工的边坡，采用较为平缓的边坡是达到较大稳定性的优先选择方案之一。

曲线 4(无张裂缝的边坡)是一种异常，说明有时计算会产生无意义的结果。这条曲线表示安全系数减小是由于坡角的减小引起滑体重量减小的结果。因为滑面上的水压力保持常数，作用在滑动面上的有效应力减小，因此抗力的摩擦力分量亦减小。当有很薄的岩石片时，水压力会把它从斜坡上浮起。这一问题的分析认为岩石片是完全不透水的，并且聚集在破坏面下的水被封堵。事实上，岩石片在被浮起之前，已破碎很长时间，那么作用在破坏面上的水压力将会消散。

曲线 5 和 6 表明排水对所研究的两个模型均不是很有效的方法。安全系数均未达到 1.5。这让人感到有些惊讶，因为排水通常是最有效和最经济的治理方法之一。在这种情况下，排水措施效果较差的原因是边坡的几何形态和破坏面的抗剪强度联合作用的结果。

曲线 7 和 8 表明，对于所研究的两个模型，采用锚杆和锚索加固边坡可能是一个有效的治理措施。要达到 1.5 的安全系数，对于无张裂缝的边坡，所需要的锚固力在边坡的长度方向上大约为 100 t/m。

长期治理工作的最终选择。对该边坡的长期治理措施最吸引人的两种方法是采用锚杆和锚索进行加固，或者减小坡角。第一种方案因加固成本高和放置在边坡中的钢筋在长期抵抗腐蚀方面的不确定性而被最后否决了。后一种考虑也许尚不能证明是正确的，但是，考虑到在本研究进行时，香港的一些工程施工质量极差，最后决定不值得冒这种风险。

最后选择的方案是将破坏面以上的岩石全部挖除，将坡角降到 35°，从而完全根治这个问题。由于香港一直需要高质量的混凝土骨料，决定将这个坡面像采石场那样加以施工。组织这项工作花费了几年的时间，在此期间，利用测压计对斜坡水位进行了监测。尽管在这一时期，道路被关闭了两次，但没有产生大的问题，边坡最终被开挖到破坏面。

Reading Material

Estimates of Shear Strength and Earthquake Acceleration

One of the most critical steps in any limit equilibrium analysis is the determination or the estimation of the shear strength parameters (c and φ) for the surface along which it is anticipated that sliding will take place. In the case of this slope on Sau Mau Ping Road, no information on shear strength was available at the time of the initial studies and so estimates had to be made on the basis of published information for similar rocks.

Hoek and Bray (1974) published a plot, reproduced in Figure 12.2, of cohesive strengths and friction angles for rocks and soils, based upon the results of published back analysis of slope failures. Superimposed on this plot is an elliptical zone which encompasses the estimated range of shear strength for sheet joints in unweathered granite. In choosing this range it was considered that the friction angle φ probably ranges from 30° for very smooth planar surfaces to 45° for rough or partly cemented surfaces. The cohesive strength c is more difficult to estimate and the range of 0.05 to 0.2 MPa was chosen on the basis of the results of back-analyses of slope failures, plotted in Figure 12.2.

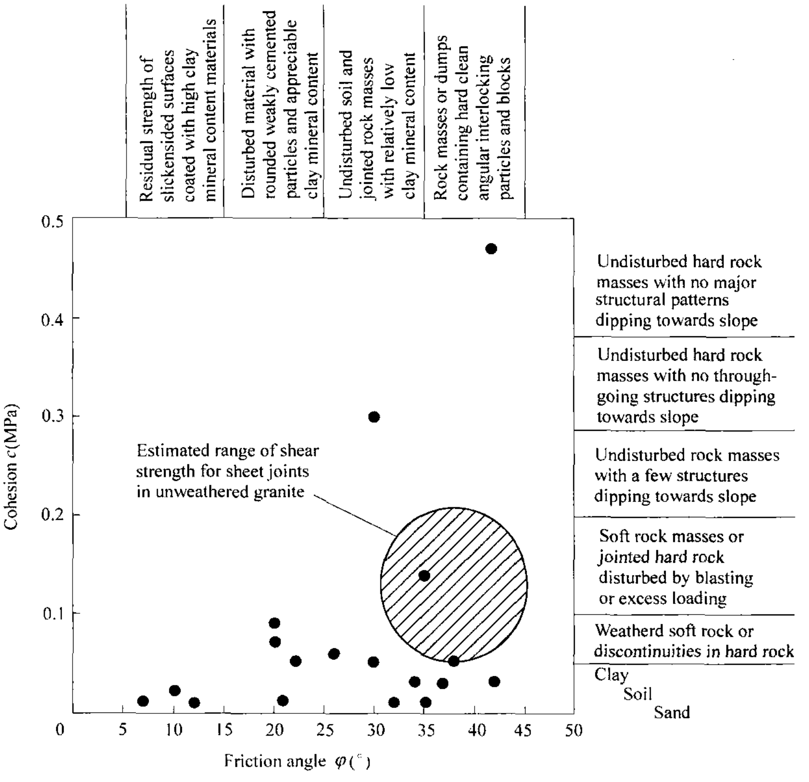


Figure 12.2 Relationship between friction angles and cohesive strengths mobilised at failure of slopes in various materials

The plotted points were obtained from published information from the back analysis of slope failures. (After Hoek and Bray 1974)

Some readers may be surprised that a cohesive strength has been assumed for joint surfaces which obviously have no tensile strength or "stickiness" as would be found in a clayey soil. In fact, this assumed cohesive strength is defined by the intercept, on the shear strength axis, of a tangent to a curvilinear Mohr envelope. This curvature is the result of the interlocking of asperities on the matching surfaces of the joints and the increase in shear strength given by this interlocking plays a crucial role in the stability of slopes.

1 Estimate of Earthquake Acceleration

Hong Kong is not considered a highly seismic region but relatively minor earthquakes are not unknown in the region. Consequently, it was felt that some allowance should be made for the possible influence of earthquake loading on the stability of the Sau Mau Ping slope.

The traditional method of incorporating the acceleration induced by earthquakes or large blasts in slope stability analyses is to add an outward force αW to the forces acting on the slope, where α is the acceleration as a proportion of g, the acceleration due to gravity. This "pseudo-static" form of analysis is known to be very conservative but, in the case of the Sau Mau Ping slope, this conservatism was not considered to be out of place.

In discussion with local engineers and geologists, the consensus opinion was that the horizontal acceleration which could be induced by a 10 years return period earthquake in the region would be approximately 0.08 g. This value was used in all of the sensitivity analyses discussed in the following sections.

2 Analysis of Mobilised Shear Strength

One method for assessing the stability of slopes is to calculate the shear strength that would be mobilised at failure and to compare this strength with the shear strength which is available along the failure surface. In the case of the Sau Mau Ping slope, this was done by substituting $F=1$ and solving for the cohesive strength c and the friction angle φ. The results of this analysis are plotted in Figure 12.3. The estimated range of available shear strength (from Fig. 12.2) is also shown on this plot.

Figure 12.3 shows that only two of the cases analysed result in conditions where the shear strength mobilised at failure falls within the estimated range of available shear strength. These two cases are designated 2 and 4 and they are for fully saturated slopes, with and without tension cracks.

From the results of the sensitivity study described above it was concluded that instability of this particular slope could occur if the slope was fully saturated and subjected to earthquake loading. Typhoons occur several times every year in Hong Kong and the intensity of precipitation during these events is certainly sufficient to saturate the slopes. As discussed earlier, minor earthquakes do occur in the region but they are not very frequent. Consequently, the chance of simultaneous saturation and earthquake loading was considered to be small and it was concluded that there was no serious short-term threat of instability of the Sau Mau Ping slope.

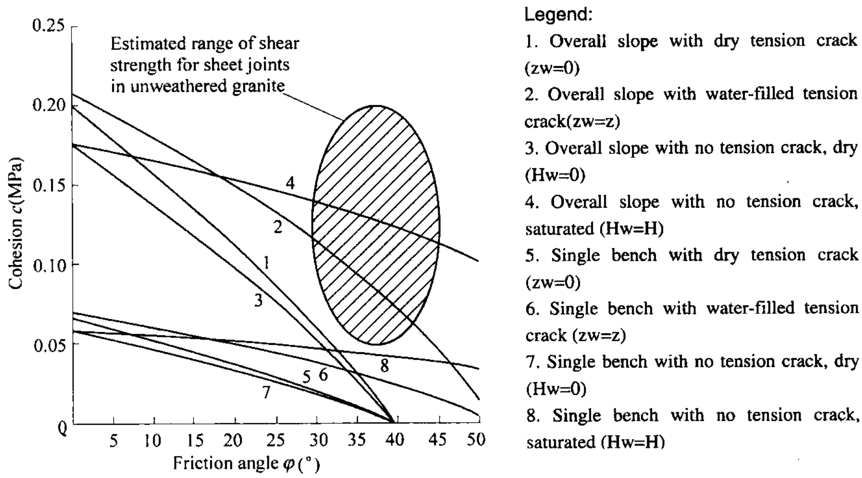


Figure12.3 Comparison of the shear strength mobilised by failure under various conditions with the estimated shear strength available on sheet joints in unweathered granite

New Words and Expressions

1.equilibrium [ˌiːkwiˈlibriəm] *n.* 平衡，均衡
2.plot [plɔt] *n.* 情节，图
3.cohesive [kəuˈhiːsiv] *a.* 有结合力的
4.friction angle 内摩擦角
5.superimpose [ˈsjuːpərimˈpəuz] *v.* 将某物置于另一物上
6.elliptical [iˈliptikəl] *a.* 似椭圆的
7.encompass [inˈkʌmpəs] *v.* 包括，包围，环绕
8.planar [ˈpleinə] *a.* 平面的，平的
9.cement [siˈment] *n.* 水泥，接合剂
10.back analysis 反分析
11.intercept [ˌintəˈsept] *n.* 截距
12.tangent [ˈtændʒənt] *n.* 切线，正切
13.curvilinear [kəːviˈliniə(r)] *a.* 曲线的；*n.* 曲线
14.curvature [ˈkəːvətʃə] *n.* 弯曲，曲率
15.interlock [ˌintəˈlɔk] *v.* 互锁，连结
16.asperity [æsˈperiti] *n.* 粗糙度，不平滑
17.acceleration [ækˌseləˈreiʃən] *n.* 加速(度)，加快
earthquake acceleration 地震加速度
18.seismic [ˈsaizmik] *a.* 地震的
19.incorporate [inˈkɔːpəreit] *v.* 结(联)合，合并
20.sensitivity analysis 敏感性分析
21.saturated [ˈsætʃəreitid] *a.* 湿透的，饱和的
22.typhoon [taiˈfuːn] *n.* 台风
23.precipitation [priˌsipiˈteiʃən] *n.* 降雨量
24.simultaneous [ˌsiməlˈteinjəs] *a.* 同时发生的

阅读材料

剪切强度与地震加速度的估算

对于任何极限平衡分析非常关键的一步是确定或估计已知滑动面上的剪切强度(c，φ)。对于秀茂坪路斜坡来说，在初始研究阶段没有剪切参数资料，于是根据已出版的类似的岩体

资料来估计该工程的剪切强度值。

Hoek 等根据出版的边坡破坏反分析结果，把岩石和土的黏聚力和内摩擦角的值绘于图 12.2，并把该图叠加到一个椭圆区上，而椭圆包括了未风化花岗岩中面状节理的抗剪强度估计值。在选定范围内，当节理面非常光滑时摩擦角 φ 为 30° 到粗糙或部分胶结的节理面时为 45°。凝聚力 c 更难估计，根据边坡破坏反分析结果，区间值为 0.05~0.2 MPa(见图 12.2)。

读者可能对一些节理面明显不具有张拉强度或黏结性就像在黏土中见到的那样而感到奇怪。事实上，假定的凝聚力是剪切轴的截距与莫尔包络曲线相切，该曲线和相应节理面粗糙连通情况有关，在斜坡稳定分析中给予的节理面剪切强度增加起关键作用。

一、地震加速度的估算

香港不是一个强地震区，但也存在一些相对小的地震。人们认为应当考虑地震荷载对秀茂坪边坡稳定性的影响。

在边坡稳定分析中，由地震或爆破所产生的综合加速度的传统计算方法是在边坡所受的力上加一个 αW 力，α 与重力加速度 g 成正比。这种拟静态分析是很保守的，但是对秀茂坪边坡而言，往往认为这种保守是合适的。

在与当地工程师和地质学家讨论中，一致认为，在该区域上，10 年为周期的地震可诱发水平地震加速度大约为 0.08 g。这个值在以下部分讨论的所有敏感分析中是可用的。

二、滑移面的剪切力分析

评价边坡稳定性的分析方法之一是计算滑移面的剪切力，然后与破坏面上的抗剪强度进行比较。对于秀茂坪边坡，将 $F=1$ 代入相关公式，解出凝聚力 c 和内摩擦角 φ。这种分析结果绘于图 12.3。可获取的剪切强度(来自图 12.2)估计范围也绘于该图上。

图 12.3 表明，在分析的各种工况条件下，只有两例滑移面上的剪切力分析结果落入估计的剪切强度范围内。在图上用 2 和 4 表示，它们是完全饱水的边坡，可能有或没有张裂缝。

从上述的敏感性分析研究结果可以得出这样的结论，如果边坡完全饱水和受地震荷载作用，边坡将处于不稳定状态。香港每年都有数次台风，这种情况下降雨足以使边坡完全饱水。正如前述，本区发生过小地震，但地震并不经常发生。因此，同时出现完全饱水和地震荷载联合作用的概率很小，秀茂坪边坡短期内不存在失稳的威胁。

Unit 13

Text

Foundations

Structures or other constructed works are supported on the earth by foundations. The word "foundation" may mean the earth itself, something placed in or on the earth to provide support, or a combination of the earth and the elements placed on it. The foundation for a multistory office building could be a combination of concrete footings and the soil or rock on which the footings are supported. The foundation for an earth-fill dam would be the natural soil or rock on which the dam is placed. Concrete footings or piles and pile caps are often referred to as foundations without including the soil or rock on which or in which they are placed. The installed elements and the natural soil or rock of the earth form a foundation system; the soil and rock provide the ultimate support of the system. Foundations that are installed may be either soil-bearing or rock-bearing. The reactions of the soil or rock to the imposed loads generally determined how well the foundation system functions. In designing the installed portions, the designer must determine the safe pressure which can be used on the soil or rock and the amount of total settlement and differential settlement which the structure can withstand.

The installed parts of the foundation system may be footings, mat foundations, slab foundations, and caissons or piles, all of which are used to transfer load from a superstructure into the earth. These parts, which transmit load from the superstructure to the earth, are called the substructure.

Footings Footings or spread foundations are used to spread the loads from columns or walls to the underlying soil or rock. Normally, footings are constructed of reinforced concrete. However, under some circumstances they may be constructed of plain concrete or masonary, when each footing supports only one column, it is square. Footings supporting two columns are called combined footings and may be either rectangular or trapezoidal. Cantilever footings are used to carry loads from two columns, with one column and one end of the footing placed against a building line or exterior wall. Footings supporting walls are continuous footings.

The sizes of footings are determined by dividing the loads to be imposed at the base of the footings by the allowable bearing pressure which can be imposed on the soil or rock of the earth. Most building codes and textbooks on foundations contain tables listing allowable bearing pressures for various types of soil and rock; however, these tables give only general classifications and descriptions of the soil or rock and must be used with caution. More specific information about

the soil or rock is normally obtained by drilling test borings, extracting soil or rock samples, performing laboratory tests on the samples, and making engineering analysis to determine suitable bearing pressures. In addition to bearing pressure, consideration must be given to the amount of settlement which may occur and the capability of the structure to withstand such settlement. If settlement is a problem it may be necessary to use an alternate foundation type rather than footings or to enlarge the footings and decrease the bearing pressure.

Grade beams may be used between exterior column footings to support walls, with the beams transferring the weight of the walls to the column footings. Beams are also used between interior column footings to act as braces or to support interior walls. Retaining walls are those walls subject to horizontal earth pressures due to the retention of earth behind them. The foundation for these walls must have sufficient frictional resistance with the soil or rock on which they rest so that they will not slide when subjected to the horizontal earth pressure. In addition, retaining walls must be designed so they will not overturn. In frost-susceptible areas, footings must be placed below the frost line.

Mat foundations Mat or raft foundations are large, thick, and usually heavily reinforced concrete mats which transfer loads from a number of columns or columns and walls to the underlying soil or rock. Mats are also combined footings, but are much larger than a footing supporting two columns. They are continuous footings and are designed to transfer a relatively uniform pressure to the underlying soil or rock. Mats are rigid and will act as a bridge over discontinuities in the soil or rock on which they are founded. Mats founded several meters below the ground surface, when combined with external walls, are termed floating foundations. The weight of the soil excavated from the ground surface to the bottom of the mat may be equal to approach the total weight of the structure. In this case, little or no new load is applied to the underlying supporting soil, and settlements of a structure may be minimal after construction.

Slab foundations Slab foundations are used for light structures wherein the columns and walls are supported directly on the floor slab. The floor slab is thickened and more heavily reinforced at the places where the column and wall loads are imposed.

Special problems Groundwater is a major problem in connection with the design and installation of foundations where a substructure is to be placed below the groundwater level. Well points, pumping from deep wells, or pumping from sumps are methods used to dewater construction sites during foundation installation. Other methods which are less often used are freezing of the water in the soul, removal of water by electroosmosis, and the installation of cutoff walls made of pilling or grout around the periphery from within the excavation. If dewatering operations are performed in an area surrounded by existing structures, precautions must be taken to project them, as the lowering of the groundwater may cause the soil on which they are supported to subside.

If a basement is partially or totally below the groundwater level, its walls must be designed to withstand the hydrostatic pressures of the water on the outside in addition to the pressure from the

soil backfill. An alternate procedure is to install a permanent system to remove water outside the walls. Some substructures below groundwater level may at times be subjected to hydrostatic uplift forces which are greater than the downward forces imposed by the structures. In these cases, provisions must be to anchor the structures to prevent them from floating upward.

Groundwater also causes problems by infiltrating through basement walls, slabs, and joints into the basement itself. This can be prevented or reduced by providing an external permanent drainage system that carries water away from the basement, by encasing the walls and slabs in an impermeable plastic membrane, or by coating the external with an asphaltic mastic to lower their permeability. Combinations of the foregoing are also used. Retaining walls and abutments often have weep holes in the lower sections through which water accumulating behind the walls or abutments can escape. The water pressure behind the walls is relieved as the water flows through the walls into an open external drainage system.

Foundations placed on expansive soils are often subjected to distressing movements unless special precautions are taken. Expansive soils are those which swell and contract excessively with varying amounts of moisture. Problems can be overcome by installing foundations below the zone of significant change in moisture content and backfilling with nonexpansive materials, by altering the soil with an admixture such as lime or cement so that volumn changes do not occur, or by providing flexibility in the structure to accommodate movements.

Underpinning of foundation is often necessary, and it may be either remedial or precautionary. Remedial underpinning is used to correct defects in existing foundations which may have settled excessively. If the structure is to be saved or returned to its original state, additional foundation support must be provided. Precautionary underpinning is used when new structures are to be installed adjacent to or beneath existing structures, as in the construction of city subways. Underpinning of foundation is a specialized construction technique. The work is generally performed in a confined space, such as the basement of a building, or in small pits excavated outside a building area. It is necessary to provide support for the loads of the existing structure while new foundations are installed. The new foundations may be footings which are placed deeper in the ground than the original foundations, or they may be piles or caissons.

Underpinning of a wall footing may be performed by excavating pits adjacent to and beneath existing foundations. The pits are small, some 0.9 m wide by 1.2 m long. Horizontal sheeting is placed in the pits as excavation proceeds to prevent caving of the walls and undermining of the structure being underpinned. When the new bearing stratum is reached, forms are placed in the pit, and concrete is poured from the new bearing stratum up to within 76 mm of the bottom of the old footing. After the new concrete has hardened, the 76 mm space is packed by hand with a mixture of sand, cement, and a small amount of water. Called grout, the mixture is packed very tightly into the space between the top of the new footing and the underside of the old footing. The pit underpinning process is repeated throughout the entire length of the wall footing. The resulting new foundation may be a continuous wall or intermittent piers.

New Words and Expressions

1.footing ['futiŋ] *n.* 底板
2.work [wə:k] *n.* 工程
3.multistory [ˌmʌltis'tɔ:ri] *a.* 多层的
4.earth-fill dam 土坝
5.ultimate ['ʌltimit] *a.* 基本的
6.mat foundation 筏板基础
7.caisson ['keisən] *n.* 沉箱
8.substructure ['sʌbˌstrʌktʃə] *n.* 下部结构
9.plain [plein] *n.* 素混凝土
10.masonry ['meisnri] *n.* 砖石结构
11.trapezoid ['træpiˌzɔid] *n.* 不规则四边形
12.cantilever ['kæntili:və] *n.* 悬臂
13.brace [breis] *n.* 支柱
14.tie [tai] *n.* 拉杆
15.retaining wall 挡土墙
16.frost [frɔst] *n.* 霜冻
17.susceptible [sə'septəbl] *a.* 敏感的
18.raft [rɑ:ft] *n.* 筏
19.floating [fləutiŋ] *a.* 浮动的
20.slab foundation 板基础
21.sump ['sʌmp] *n.* 贮槽
22.electroosmosis [i'lektrəuɔs'məusis] *n.* 电渗
23.cutoff [kʌtɔf] *n.* 切开
24.periphery [pə'rifəri] *n.* 周围
25.subside [səb'said] *vi.* 下沉
26.infiltrate ['infiltreit] *v.* 渗透
27.encasing [in'keisiŋ] *n.* 砌壁
28.asphaltic mastic 沥青树脂
29.weep [wi:p] *n.* 排水
30.foregoing [fɔ:'gəuiŋ] *a.* 以上的
31.relieve [ri'li:v] *v.* 减轻
32.distressing [di'stresiŋ] *a.* 令人苦恼的
33.swell [swel] *v.* 膨胀
34.contract ['kɔntrækt, kən'trækt] *v.* 收缩
35.admixture [æd'mikstʃə] *n.* 掺和物
36.accommodate [ə'kɔmədeit] *v.* 适应
37.underpinning [ʌndə'piniŋ] *n.* 托换基础
38.remedial [ri'mi:diəl] *a.* 修补的
39.precautionary [pri'kɔ:ʃənəri] *a.* 预防的
40.sheet [ʃi:t] *n.* 板
41.cave [keiv] *v.* 坍陷
42.undermine [ˌʌndə'main] *vt.* 潜挖
43.intermittent pier 间隔板

基 础

建筑物或已建成的工程是由基础下的地基土支承着的。"基础"一词意味着土本身或在土内(或其上)布置的物体作为支承体，或作为土和在它上面布置的构件的联合体。多层办公建筑物的基础一般是混凝土底板与土(或底板置于其上的岩石)的联合体。土坝的基础是天然的地基土或岩石。混凝土底板或桩及其桩帽常被看做基础，而不包括它们所涉及的地基土或岩石。所建立的构件和天然的土或岩石形成了基础系统；土和岩石为这一系统提供了基本支撑。已建立的基础不是由地基土支撑就是由岩石支撑。土和岩石对于增加给它们荷载的反应，一般决定了基础系统功能的好坏程度。在设计安装的基础部分中，设计者必须确定安全压力即在土或岩石上可能受到的压力以及建筑物可能承受的总沉降或沉降差。

基础系统已建的部分是底板、筏板、板基础和沉箱或柱，所有这些形式把上部结构荷载传递给地基土。把上部结构荷载传给地基土的部分叫下部结构。

底板 底板或伸展性基础是通过柱或墙把上部荷载传给下面的土或岩石。一般来说底板由预应力混凝土构成。然而在一些环境下，底板也可由素混凝土和砖石构成，当每个底板仅

支撑一根柱时，底板是方形。底板支撑两个柱称组合底板，它可能是矩形或不规则四边形。悬臂底板承受两根柱子的荷载，其中一根柱子和底板的末端对着建筑物轮廓线或外墙。底板支撑墙是连续底板。

底板的尺寸由底板地基受的荷载除以土或岩石允许承载压强而得到。对基础来说大部分规范或教科书上都有表格列出了不同类型土和岩石的允许承载力值；然而，这些表格仅给出了土和岩石一般性分类和描述，使用时要谨慎。关于土和岩石更详细的信息一般可通过钻探试验孔、取土和岩石试件、在实验室测试试件得到，并做工程分析来确定适当的承载力值。除承载力外要考虑到总的沉降以及结构承受这样沉降的可能性。如果沉降是一个问题，采用置换基础是必要的而不是用底板或扩大底板和减少承载力。

梯级梁可在外柱底板和支撑墙之间使用，用梁把墙的重量传给柱底板。梁也在内柱底板之间使用，其作用作为支柱(拉杆)或支撑内墙。挡土墙是承受墙后土体引起的水平土压力的墙体。对于墙基础来说，当其受水平压力时在墙与土(或岩石)之间要有足够的抗滑力，以至于墙不会滑动。另外，为了防止墙倾覆也应做挡土墙设计。在冻融敏感区，底板必须放置在冻融线以下。

筏板基础 筏板基础是大的、厚的，常常是预应力混凝土板，通过数根柱基或柱与墙联合体把荷载传给下部的土或岩石。筏板也可是相连的底板，但筏板要比支撑两个柱的底板大些。筏板可谓是连续底板，它们被设计用来把相对均一的压力传给下面的土或岩石。筏板是刚性的，当支撑其的土或岩石不连续时，其作用类似桥。筏板可建在地表以下几米处，当与外墙连接时，则称为浮动基础。从地表到筏板底部所开挖土的重量可接近于建筑物的总重量。在这一情况下，很少或没有新的荷载施加于下部的支撑上，在建筑物建成后，建筑物沉降为最小。

板基础 板基础用于轻型建筑物，把柱和墙直接支撑在底板上。在柱和墙施加荷载的位置，底板是厚重的预应力混凝土板。

一些特殊问题 在设计和建设下部结构应布置在地下水位以下的基础时，地下水是一个主要问题。在基础安装期间，从深井中抽取基坑中的水或从贮水槽中抽取基坑中的水，都可用于降低地下水位。其他一些不常用的办法是把核心部分的水加以冻结，用电渗来转移地下水，安装切开墙制成堆垛或从开挖内侧周围灌浆。如果在已有建筑物周围区域上进行抽水，必须对建筑物注意保护，因为地下水位降低可能会引起建筑物下的土下沉。

如果地下室部分或全部在地下水位以下，墙体设计除了能承受墙后的土压力外还必须设计成能承受墙外的静水压力。一个可选取的方法是在墙外建立能抽取地下水永久系统。位于地下水位以下的一些下部结构时常可能受到扬压力作用，且大于建筑物向下的自重。在这种情况下，对建筑物应进行锚固，以防止建筑物向上浮托。

地下水也会通过地下室边墙、底板和其连接处渗透引起一些问题。这个情况可以防止或减少，通过做永久排水系统从地下室把水排去，或用不透水的塑料膜包住壁墙和板墙做防护，也可用沥青树脂对外部墙体做防护以降低其渗透性。以上措施也可联合使用。挡土墙和墩柱在其下部有排水孔，这样在挡土墙和墩柱后面汇积的水可流走。当水通过墙流到外部排水系统时，墙后水压力可减少。

在没有特殊防护条件下，建立在膨胀性土上的基础会发生有害的移动。膨胀土在不同的

含水条件下会发生过分的膨胀和收缩。把基础建在含水量明显变化带以下并填充非膨胀材料可克服这一问题，在土中加入石灰或水泥的混合物改变土的组成但体积不变，或使上部结构更加柔性以能适应所发生的移动也是可行的办法。

对基础进行托换常常是必须的，也可对基础用修补或预防性办法。修补性托换常可用于修理有缺陷的基础，这种基础沉降范围往往很大。假如建筑物要加以补救或恢复原貌，对基础做支护加固则非常必要。当一个新建筑物是靠近另一建筑物或在其下，采用托换基础，如城市地铁建设。基础托换是一专门的建设技术。这一工作一般是在有限的空间进行，如在一个建筑物地下室或在建筑物以外开挖坑槽。当建设一个新基础时对已存在的建筑物荷载加以支护是必要的。新基础可以是底板，它在地表以下深度比原有基础要深，新基础也可是柱或沉箱。

对已有基础附近或在基础下开挖坑槽用墙底板托换方法是可行的。坑一般不大，0.9 m 宽、1.2 m 长。在开挖过程中，坑中要布置水平板以防止墙坍陷和脱换基础潜挖。当到达新的承载层时，把模子放入坑中，浇混凝土从新承载层至原有底板向上 76 mm 范围内。在新的混凝土变硬后，用砂、水泥和少量水混合物对 76 mm 空隙进行人工封堵。所谓灌浆是把新底板的顶部和原底板下面之间的空间用混凝土紧密地加以封堵。基坑的托换基础过程是在整个墙底板长度上重复进行的。新的托换基础可以是连续墙，也可以是间隔墩。

Reading Material

Foundation Engineering

One indisputable fact is this: whatever the shape of a building or structure and whatever the nature and number of its supports, the whole weight of the building must come down to, and be supported by the ground. It is therefore essential that, for any proposed structure, sufficient knowledge be obtained of the nature of the supporting soil and its load-bearing capacity.

The purpose of a foundation is to convey the weight of a building to the soil in such a manner:

(1)That excessive settlement will not occur;

(2)That differential settlement of various sections of the building, which causes cracks in the structure, will not occur;

(3)That the soil will not fail under its load, thus causing no collapse of the building.

Compared with structural materials, such as steel and timber, soil is difficult to investigate scientifically. It can vary considerably in its properties on one building site both in horizontal and vertical directions.

Until the 20th century, foundations were constructed mainly on the basis of experience. For important structures, deep trial pits were dug so that the soil could be examined for some distance below the surface, and sometimes loading tests on small areas at the bottom of the pits, were made to estimate the safe-bearing capacity of the soil.

Some time about 1920 there began a more scientific approach to the behavior of soils. One of

the earliest names, and a most important one, connected with this new science, is Dr. Karl Terzaghi, who made an extensive study of the properties of soils. Since 1920 much research has been carried out in many countries; many tests (site and laboratory) have been devised, and there is now a considerable literature on the subject of soil mechanics. Modern site investigations for important structures are carried out by specialist firms who have trained personnel, equipment for drilling and boring and for extracting samples of soil, and facilities for making site and laboratory tests.

All the material forming the crust of the earth likely to be affected by the pressure of structures is divided by engineers into two major groups: rocks and soils. The term"rock"is reserved for hard, rigid, and strongly cemented material, while "soil" is applied to the comparatively soft and loose materials.

Soils without of organic deposits such as peat are broadly divided into two groups: cohesive and non-cohesive. Silts and clays are cohesive, while granular materials such as sands and gravels are non-cohesive.

Owing to the weight of a building or other structure, there is bound to be a certain amount of settlement. It was stated previously that force cannot be applied to any material without causing deformation. The total settlement of a building takes place in two stages:

(1)Immediate settlement, as the building is being erected, due to elastic and plastic deformation of the soil.

(2)Consolidation settlement caused by the sequeezing-out of water contained in the pores of the soil and thus compressing the soil to a smaller volume.

From the settlement point of view, non-cohesive soils such as sands and gravels are not very troublesome since they are only moderately compressible and are very permeable (a permeable material is one which allows water to pass through it easily). Consolidation settlement due to sequeezing-out of pore water therefore occurs very quickly during and soon after the erection of the structure, and is comparatively small. Special attention, however, must be given to loose sands, which can show appreciable settlement if subjected to vibration.

Cohesive soils such as clay have very low permeability, which means that squeezing of water from the pores due to consolidation settlement of the building is a slow process. Furthermore, the compressibility of most clays and silts is appreciable and there is a compressibility volume reduction under pressure. The final settlement of a structure founded on clay may therefore not occur until some years after erection and must be allowed for in design calculations.

Clay is also a troublesome material when encountered in shallow foundations (for houses and other small buildings). Cohesive soils dry out in the summer and spring; surface cracks can occur which may extend to about 0.3 m in Britain.

Precast Piles Precast piles, which are usually square or octagonal in cross-section, are driven into the soil by repeated blows from a falling weighted or from a steam hammer. The piles are driven in until a certain number of blows produce only a small further penetration which has been predetermined by calculations in accordance with the loads, and the piles will be called upon

to supports.

A simple illustration is that of knocking a timber stake into soil. The deeper the stake is driven into the ground, the greater is the frictional resistance and the harder it is to drive the stake downwards. When a pile is driven a sufficient distance, the resultant load it has to carry is usually supported partly by frictional force on the sides of the pile and partly by the bearing resistance of the soil under the foot of the pile.

If the strata are of such a nature that the soil can offer negligible frictional resistance, the pile must be driven until it meets a hard stratum such as rock capable of supporting the full load. Alternatively the soil may be of such a nature that most of the resistance to the downward action of the weight of the building is provided by frictional resistance.

In supporting their loads, piles act as columns, except that the soil provides lateral restraint.

Another method, as used by the Franki Compressed Pile Co,consists in driving a steel tube to the required depth and filling it with in-situ concrete. First , the bottom of the tube is sealed by a temporary gravel plug. The tube is then driven to the required depth by blows on this plug from a long heavy cylindrical hammer. Concrete is then placed in the tube and rammed so that a bulbous foot is produced (thus increasing bearing resistance). As the rammed concrete approaches the ground surface , the tube is gradually withdrawn.

Bored Piles Driven piles displace and compress the soil. Then piles are bored in situ , the soil is removed by special boring tools to form cylindrical holes equal to the depths of the prepared piles.Steel reinforcement is then inserted and concreted rammed in to form the pile, which frequently has a bulbous base due to heavy ramming of the first batch of concrete. In addition, bored piles are useful where headroom is restricted so that it is impossible to have long lengths of precast piles projecting above ground level.

Cylinder Piles Cylinder foundations, 2 m or more in diameter, have been employed for many years, the holes being made by excavating soil with hand or mechanically operated grabs. During the last few years new methods have developed for forming these large diameter holes. In one system, first used in the United States, angles(drills), varying from 1 m to 2.3 m in diameter, are used for boring holes which may be as much as 25 m deep or more. The bottoms of the holes are usually enlarged by special drilling-out tools to a diameter of 5 m in the case of the 2.3 m diameter cylinders, and 2.3 m for the 1 m diameter cylinders. Large bearing areas are thus obtained; one of these piles in the London clay was designed to supporting a load of 2 000 tons. One advantage of a large-diameter cylinder pile is that a heavily loaded column can often be supported directly by one pile, thus saving the cost of a pile cap, which is required when the column has to be supported by a number of small-diameter piles.

Piles Caps When small-diameter driven or bored piles are used, the number of piles required to support one column can be obtained by dividing the column load to the safe load for one pile. The load from the column must be transferred to the piles by means of a foundation called a pile cap. Reinforcement is required in the cap to resist bending stresses, etc.

New Words and Expressions

1.indisputable [ˌindis'pju:təbl] *a.* 无可争辩的
2.nature ['neitʃə] *n.* 特性
3.convey [kən'vei] *vt.* 搬运
4.trial [traiəl] *n.* 试验
5.bore [bɔ:] *v.* 开挖，钻孔
6.peat [pi:t] *n.* 泥炭(土)
7.bind [baind] *v.* 必定
8.octagonal [ɔk'tægənl] *a.* 八角形的
9.blow [bləu] *n.* 打击
10.predetermine ['pri:di'tə:min] *vt.* 预定
11.be called upon to 被用来
12.stake [steik] *n.* 木桩
13.resultant [ri'zʌltənt] *a.* 综合的
14.restraint [ris'trein] *n.* 约束力
15.plug [plʌg] *n.* 插头
16.ram [ræm] *vt.* 锤击，振动
17.bulbous['bʌlbəs] *a.* 球形的
18.displace [dis'pleis] *vt.* 取代，置换
19.reinforcement [ˌri:in'fɔ:smənt] *n.* 钢筋
20.headroom ['hedru:m] *n.* 顶空间
21.precast ['pri:'kɑ:st] *a.* 预制的
22.projecting [prə'dʒektiŋ] *a.* 伸出的
23.grab['græb] *n.* 抓斗，开挖机
24.angle ['æŋgl] *n.* 情况，角度
25.load-bearing capacity 承载能力
26.crack [kræk] *n.* 裂缝
27.granular ['grænjulə] *a.* 颗粒状的
28.gravel ['grævəl] *n.* 砾石，卵石
29.immediate settlement 瞬时沉降
30.consolidation settlement 固结沉降
31.pore water 孔隙水
32.shallow foundation 浅基础
33.stratum [streitəm] *n.* 地层
34.in-situ 现场
35.bored pile 钻孔桩
36.pile cap 桩帽

阅读材料

基础工程

一个无可争辩的事实是：不管建筑物或结构物的形状怎样，也不管支承物的性质和数量，建筑物的整个重量必然向下传递并由地基支承。因此，对任何建筑物来说，对支承土的性质和它的承载能力进行充分了解是一个基本的问题。

修建基础的目的是承载建筑物的重量，对土来说应是这样：

(1)广泛的沉降不会发生；

(2)建筑物中不同部分差异性沉降在建筑物中不会发生裂缝；

(3)土在本身荷载作用下不发生破坏，建筑物不会发生坍陷。

以建筑材料如钢、木材等与土比较，土调查起来颇为困难。在同一建筑现场，土在水平方向和垂直方向其性质会有相当大的变化。

直到 20 世纪，基础建设主要靠经验。对一些重要建筑物，要挖一些深坑来检验地表下一定深度处的情况，有时在试坑底部做荷载试验，以估算土的安全承载能力。

大约在 1920 年前后，在土的特性上开始了更加科学的研究。在这一领域最早最为重要的一个人就是 Karl Terzaghi 博士,他对土的特性做了广泛研究。从 1920 年起许多国家进行了

这方面研究；设计了许多试验(室内和现场)，目前在土力学方面文献颇多。对一些重要建筑物的现场调查由一些专家公司完成，他们有经过专业培训的人员，取土样和钻探设备以及室内实验设备。

受建筑物压力作用的地壳材料被工程人员分成两组即岩石和土。岩石一词表示坚硬、刚性和很强的胶结材料，土则表示相对较软和疏松的材料。

没有有机质的土如泥炭土，被广泛地分成两组：有凝聚力和无凝聚力。粉砂土和黏土是有凝聚力的，砾状材料如砂和砾石无凝聚力。

建筑物和其结构物在自重作用下，一定会发生一定量的沉降。过去曾说过，有力就有变形。建筑物总的沉降分为两个阶段：

(1)瞬时沉降是在建筑中引起的，即土会发生弹性和塑性变形；

(2)固结沉降是由土中孔隙水被排出，使土的体积减少。

从沉降的观点考虑，非黏性土如砂和砾石不存在这一问题，因为它们有一定压缩性和很大的渗透性(渗透材料是指水很容易通过的材料)。固结沉降是由水挤出引起的，因而在建筑物建设及建成以后很快会发生，沉降相对不大。然而，要特别注意的是松砂，当松砂受到振动会有可感知的沉降。

有黏性的土如黏土渗透性很低，这意味着由建筑物所引起的固结沉降使孔隙水被排出是一个很漫长的过程。因此，大部分黏土和砂土的压缩性是明显的，在压力下可压缩的体积会减少不小。在黏土上所建建筑物最终沉降在建成以后若干年并没完成，在设计计算中必须考虑到这一点。

在浅基础中黏土仍是麻烦的材料(如房子和一些小型建筑物)。在夏天和春天黏性土会干燥，并产生收缩裂缝，在英国这样的裂缝达 0.3 m。

预制桩　预制桩在断面上通常是方形或八角形的，它由落体重物或气锤重复打击而进入土中。每次锤击桩，导入的深度会越来越小，一直到按荷载计算得到的预定的深度，这时桩被用来作为支撑物。

以打入土中的木桩为例做一简单的说明。木桩打入土中越深，摩擦阻力越大，向下打的时候越困难。当桩导入足够深度后，总的力由以下两部分承担，一为桩周围的摩擦力，二为桩底端土的抗阻力。

假如地层为摩阻力可忽略不计的天然状态土，桩应打到具有能支撑全部荷载的坚硬岩石。而所选土也可能有如此的特性，即建筑物重量向下作用的大部分力由摩阻力来承担。

在支承上部荷载时，桩的作用被看做支撑柱，当然土提供了侧向约束。

另外一种方法像 Franki 压桩公司所提出的那样，把一个钢管打到要求深度并在管内填混凝土。首先，管底端用一个暂时砾状插头封起来。然后，利用一个重而长的圆柱形锤头来冲击桩头，把管子打到要求深度。再把混凝土放入管中并加振捣，以便形成球形桩脚(增加承载阻力)。当振捣的混凝土到达地表，管子被逐渐地抽出来。

钻孔桩　用桩来置换和挤压土体。在现场用桩打孔，并用专门的钻具把土移出形成一个圆柱孔，其深度等于设计桩深。随后把钢筋插入，浇混凝土振捣构成桩，该桩通常会有球形底板，这是由第一批混凝土受到重型振捣形成的。另外，钻孔桩应用条件是顶部空间受到限制以致预制桩长度在地面以上不可能伸展太长才采用这种办法。

圆柱桩　直径是 2 m 或更大的圆柱基础，多年来一直得到应用，钻孔用人工或机械抓斗来形成。在最近几年为了形成这样一个大直径钻孔提出了一些新的方法。这一情况首先在美国得到应用，用一个直径 1 ~ 2.3 m 的钻孔机钻 25 m 或更深。当孔底钻孔直径是 2.3 m 时用专门钻具把它扩成 5 m，当直径是 1 m 时扩成 2.3 m。一个大的承载面积在底部形成；这一方法在伦敦黏土中得到应用，设计支承荷载为 2 000 t。这种大直径的圆桩优点在于上部重量大，如果需要几个小直径支承时，可由一个柱承担，这样上部桩帽就可省下，使费用减少。

柱帽问题　当使用小直径的圆柱桩或钻孔桩时，几个小直径桩来支承上部一个立柱，这样把立柱荷载分到每个桩的安全荷载范围内。立柱荷载用柱帽来传递给桩。在桩帽中要布置钢筋以承受弯应力。

Unit 14

Text

Dams

The first dam for which there are reliable records was built on the Nile River sometime before 4000 B. C. It was used to divert the Nile and provide a site for the ancient city of Memphis. The oldest dam still in use is the Almanza Dam in Spain, which was constructed in the sixteenth century. With the passage of time, materials and methods of construction have improved, making possible the erection of such large dams as the Nurek Dam which is being constructed in the Former Soviet Union on the Vaksh River near the border of Afghanistan. This dam will be 333 m high, of earth and rock fill. The failure of a dam may cause serious loss of life and property; consequently, the design and maintenance of dams are commonly under government surveillance. In the United States over 30 000 dams are under the control of state authorities. The 1972 Federal Dam Safety Act (PL 92-367) requires periodic inspections of dams by qualified experts. The failure of the Teton Dam in Idaho in June 1976 added to the concern for dam safety in the United States.

1 Types of Dams

Dams are classified on the basis of the type and materials of construction, as gravity, arch, buttress, and earth. The first three types are usually constructed of concrete. A gravity dam depends on its own weight for stability and is usually straight in plane although sometimes slightly curved. Arch dams transmit most of the horizontal thrust of the water behind them to the abutments by arch action and have thinner cross sections than comparable gravity dams. Arch dams can be used only in narrow canyons where the walls are capable of withstanding the thrust produced by the arch action. The simplest of the many types of buttress dams is the slab type, which consists of sloping flat slabs supported at intervals by buttresses. Earth dams are embankments of rock or earth with provision for controlling seepage by means of an impermeable core or upstream blanket. More than one type of dam may be included in a single structure. Curved dams may combine both gravity and arch action to achieve stability. Long dams often have a concrete river section containing spillway and sluice gates and earth or rock-fill wing dams for the remainder of their length.

The selection of the best type of dam for a given site is a problem in both engineering

feasibility and cost. Feasibility is governed by topography, geology and climate. For example, because concrete spalls when subjected to alternate freezing and thawing, arch and buttress dams with thin concrete sections are sometimes avoided in areas subject to extreme cold. The relative cost of the various types of dams depends mainly on the availability of construction materials near the site and the accessibility of transportation facilities. Dams are sometimes built in stages with the second or later stages constructed a decade or longer after the first stage.

The height of a dam is defined as the difference in elevation between the roadway, or spillway crest, and the lowest part of the excavated foundation. However, figures quoted for heights of dams are often determined in other ways. Frequently the height is taken as the net height above the old river bed.

2 Forces on dams

A dam must be relatively impervious to water and capable of resisting the forces acting on it. The most important of these forces are gravity (weight of dam), hydrostatic pressure, uplift, ice pressure, and earthquake forces. These forces are transmitted to the foundation and abutments of the dam, which react against the dam with an equal and opposite force, the foundation reaction. The effect of hydrostatic pressure caused by sediment deposits in the reservoir and of dynamic forces caused by water flowing over the dam may require consideration in special cases.

The weight of a dam is the product of its volume and the specific weight of the material. The line of action of this force passes through the center of mass of the cross section. Hydrostatic forces may act on both the upstream and downstream faces of the dam. The horizontal component H_h of the hydrostatic force is the force on a vertical projection of the face of the dam, and for unit width of dam it is

$$H_h=\gamma h^2/2 \tag{14.1}$$

where γ is the specific weight of water; h is the depth of water. The line of action of this force is $h/3$ above the base of the dam. The vertical component of the hydrostatic force is equal to the weight of water vertically above the face of the dam and passes through the center of gravity of this volume of water.

Water under pressure inevitably finds its way between the dam and its foundation and creates uplift pressures. The magnitude of the uplift force depends on the character of the foundation and the construction methods. It is often assumed that the uplift pressure varies linearly from full hydrostatic pressure at the upstream face (heel) to full tail-water pressure at the downstream face (toe). For this assumption the uplift force U is

$$U = \gamma (h_1 + h_2) t / 2 \tag{14.2}$$

where t is the base thickness of the dam; h_1 and h_2 are the water depths at the heel and toe of the respectively. The uplift force will act through the center of area of the pressure trapezoid (Fig.14.1).

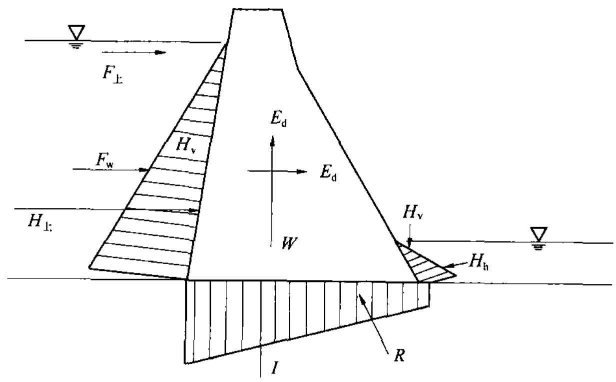


Figure 14.1 Free-body diagram of the cross section of a gravity dam

Actual measurements on dams (Fig. 14.1) indicate that the uplift force is much less than that given by Eq.14.2. Various assumptions have been made regarding the distribution of uplift pressures. The U.S. Bureau of Reclamation sometimes assumes that the uplift pressure on gravity dams varies linearly from two-thirds of full uplift at the heel to zero at the toe. Drain is usually provided near the heel of the dam to permit the escape of seepage water and relieve uplift.

New Words and Expressions

1.reliable [ri'laiəbl] *a.* 可靠的，可信的
2.the Nile River *n.* 尼罗河
3.divert [di'vəːt] *v.* 使转向，分(引)水
4.Memphis 孟菲斯(古城)
5.the Almanza Dam 阿尔曼扎坝
6.Nurek Dam 努列克大坝
7.Soviet Union 苏联
8.Vaksh river 瓦赫什河
9.Afghanistan [æf'gænistæn] *n.* 阿富汗
10.maintenance ['meintinəns] *n.* 维持，维护
11.surveillance [səː'veiləns] *n.* 监视(督)
12.authority [ɔː'θɔriti] *n.* 当局，官方
13.Teton dam 提堂坝
14.buttress ['bʌtris] *n.* 支撑墩；*vt.*支持
15.thrust [θrʌst] *n.* 推力
16.abutment [ə'bʌtmənt] *n.* 桥台，支座
17.cross section 横断面，剖面(图)
18.comparable ['kɔmpərəbl] *a.* 类似的,可比的
19.canyon ['kænjən] *n.* 峡(深)谷
20.at intervals 每隔一段时间(距离)
21.with provision for 考虑到
22.blanket ['blæŋkit] *n.* 覆盖层
23.remainder [ri'meində] *n.* 剩余，残余
24.spall [spɔːl] *v.* 剥落，裂开
25.spillway ['spilwei] *n.* 溢洪(泄洪)道
26.sluice [sluːs] *n.* 水闸
27.feasibility [ˌfiːzə'biləti] *n.* 可行性，可能性
28.topography [tə'pɔgrəfi] *n.* 地形，地貌
29.thaw [θɔː] *v.* 融化，融解
30.accessibility [ˌækəsesi'biliti] *n.* 易接近的，可到达的
31.impervious [im'pəːvjəs] *a.* 不能渗透的
32.hydrostatic [ˌhaidrəu'stætik] *a.* 静水力学的，流体静力学的
33.uplift [ʌp'lift] *n.* 扬压力，浮力
34.sediment ['sedimənt] *n.* 沉积[物]，沉积物
35.reservoir ['rezəvwɑː] *n.* 水库，蓄水池
36.specific weight 比重

37.projection [prə'dʒekʃən] *n.* 投影
38.heel [hi:l] *n.* 脚跟，坝踵
39.trapezoid ['træpizɔid] *n.* 阶梯形
40.bureau [bjuə'rəu] *n.* 局，科，处
41.reclamation [ˌreklə'meiʃən] *n.* 开垦
42.the U.S. bureau of reclamation 美国垦务局

大 坝

在人类历史上有可靠记载的第一座大坝是在公元前 4000 年修建在尼罗河上的。它被用于引尼罗河的水并为古城孟菲斯使用。至今仍在使用的最古老大坝是西班牙 16 世纪修建的阿尔曼扎坝。随着时间推移，建筑材料和施工方法有了很大改进，使修筑努列克大坝成为可能，该坝由前苏联修筑，靠近阿富汗边界的瓦赫什河。坝高 333 m，为土石坝。大坝失事会导致严重的生命和财产损失，因此坝的设计和维护通常在政府的监控下进行。美国有 3 万多座坝由各州政府控制。1976 年美国联邦大坝安全法(PL 92-367)规定大坝需要有经验的专家定期检查。1976 年 6 月在爱达荷州的提堂大坝失事，使美国对大坝安全更为关注。

一、坝的类型

根据形式和建筑材料，坝分为重力坝、拱坝、支墩坝和土坝。前三种坝通常要用混凝土建成。重力坝依靠自重维持稳定，通常在平面上为直线状，虽然有时略带弯曲。拱坝通过拱作用把坝后的水力传给坝肩，它比重力坝横断面要单薄。拱坝适合于狭窄的山谷，两坝肩承受由拱作用传来的推力。在支墩坝中最简单的形式是面板坝，它由许多倾斜薄面板组成，这些面板由每隔一定距离的支墩来支承。土坝是由土或石料填筑而成的土堤，为了防止渗漏修筑了不透水的心墙或上游铺盖。在一个坝址区可能会有多种坝型。为了达到稳定，把重力坝和拱坝组合在一起构成曲面坝。一些长坝在河道部分是混凝土，它包含溢洪道和泄水闸门，坝的其余部分由土或岩石材料筑成。

对既定坝址，坝型的选择要考虑工程可行性和费用。可行性主要由地形地貌、地质和气候控制。例如，由于受到冻融作用可引起混凝土剥落，故在严寒地区有时不采用断面单薄的混凝土拱坝和支墩坝。各类坝型的相对费用主要取决于坝址附近建筑材料的可用性及运输设施情况。大坝有时分期施工，第二期或以后几期工程，往往在第一期工程后十年或者更长的时间。

坝高是指行车道或溢洪道顶与开挖基础最低点之间的海拔高差。然而，引用的坝高数据常常用别的方法确定。一般常取原河床以上的净高度作为坝高。

二、作用在大坝上的力

坝必须是相对不透水的，并能承受作用在其上的力。在这些力中最重要的是重力(坝体质量)、静水压力、扬压力、冰压力和地震力。这些力传给坝基和坝肩，而坝基和坝肩对坝体产生一个大小相等、方向相反的基础反力。在某些特殊情况下，还要考虑水库中的淤积引起静水压力的影响以及坝顶溢流所产生的动力作用。

坝的自重是坝的体积和材料容重的乘积。该力的作用线通过坝横断面的重心。在坝的上游面和下游面会受到静水压力作用。静水压力的水平分力 H_h 是作用于垂直坝面上的力，对于单位宽度坝体其值为

$$H_h=\gamma h^2/2 \qquad (14.1)$$

式中：γ为水的比重；h 为水的深度。该力的作用线在坝基以上 $h/3$ 处。静水压力的垂直分力等于在坝面上面的水的垂直重量，并通过该水体的重心。

处于压力作用下的水在大坝和坝基之间接触面必然会建立起它的行为方式并产生扬压力。扬压力的大小取决于基础的特征和施工方法。经常假定扬压力变化是线性的，即从上游面的库水位全水头到下游面坝址处的整个尾水压力。根据这个假设，扬压力 U 为

$$U=\gamma(h_1+h_2)t/2 \qquad (14.2)$$

式中：t 为大坝基础宽度；h_1 和 h_2 分别为大坝坝踵和坝址水的深度。扬压力的作用线通过梯形的重心(见图 14.1)。

大坝的实测资料表明(见图 14.1)扬压力远小于式(14-2)所给的值。扬压力的分布存在各种各样的假定。美国垦务局认为重力坝的扬压力呈线性变化，在上游坝踵处取全部扬压力的2/3，下游坝址处为 0。在坝踵处通常有排水设施，以便排除渗水，降低扬压力。

Reading Material

Dams

Large modern dams are constructed across rivers to store and control vast quantities of water. And it can be used for irrigation, electric power generation, flood control, navigation, public water supplies, industrial water supplies and recreation. Some dams serve only one or a few of these purposes, but most modern dams serve several functions and therefore are called multipurpose dams.

In recent times, the demands on water resources caused by expanding populations and economies have increased the need to build dams for water storage. In the United States, for water diverted into waterworks structures, the average water consumption per capita was 137 gallons per day. This figure includes residential, commercial, and industrial use of water in a community. In towns where are large industrial users of water, the water requirement per capita is even higher because, for example, it takes 65 000 gallons of water to make a ton of steel and 10 gallons of water to refine a gallon of gasoline.

Although dam building is a key means for controlling and using water resources for the benefit of mankind, it sometimes presents problems because a dam blocks the river, and impedes navigation by vessels and migration by fish. Where a channel for river vessel is required, navigation locks are built alongside the dam. Where fish migration is important, fish locks similar to locks for vessels are provided. Fish ladders also are built so that valuable fish, such as salmon, can swim around a dam. The fish enter at the lowest of a series of ascending pools and leap from pool to pool until they get to the reservoir level.

An advanced technology is needed in building a large dam and its related facilities so that they will be economical, useful, and safe from failure. Aerial photographs often are used in the

preliminary stages of exploration to locate major geological features at a site. Expert knowledge of hydrology, geology, hydraulics, and other sciences is applied to solve the complex problems encountered in analyzing the foundation rock and soil, laying bare the riverbed at the dam site, and designing and constructing the dam and related facilities. Each material, such as earth, rock or concrete, to be used in building the dam is selected to produce the desired results in the most economical way at a particular site. Careful analysis and study of each material are made to ensure that the dam will be impervious to water and will be heavy and strong enough to resist the reservoir water pressure against the face of the dam. In high dams, this pressure is tremendous; at the base of the Hoover Dam, for example, the water exerts a pressure of 310 MPa.

New Words and Expressions

1. construct [kən'strʌkt] *vt.* 建造
2. multipurpose ['mʌlti'pəːpəs] *a.* 多功能的
3. register ['redʒistə] *n.* 记录表
4. divert [di'vəːt] *v.* 分水，引水
5. capita ['kæpitə](caput 的复数)总人数
6. residential [ˌrezi'denʃəl] *a.* 居住的
7. requirement [ri'kwaiəmənt] *n.* 需求量
8. block [blɔk] *v.* 截断，封锁
9. impede [im'piːd] *v.* 阻碍，妨碍
10. migration [mai'greiʃən] *n.* 迁移，流动
11. alongside *prep.* 靠在……旁边
12. salmon ['sæmən] *n.* 鲑鱼
13. ascending [ə'sendiŋ] *a.* 向上的
14. leap [liːp] *v.* 跳过，跃过
15. aerial ['εəriəl] *a.* 航空的
16. hydraulics ['hai'drɔːliks] *n.* 水力学
17. riverbed ['rivəbed] *n.* 河床
18. tremendous [tri'mendəs] *a.* 巨大的
19. psi =pound per square inch 磅/平方英寸
20. safe from 免于遭受……之患
21. aerial photograph 航摄照片
22. be applied to 应用于
23. lay bare 揭开
24. impervious to water 防水的，不透水的
25. at the base of 在……基部
26. per capita 每人

阅读材料

大 坝

横跨河流建设的现代大坝主要用于蓄水和控制巨大的水源。此水库的水可用于灌溉、发电、防洪、航运、公共用水、工业用水和娱乐。一些坝只有其中一种或几种用途，但大部分大坝用途是多方面的，因此叫做水利枢纽(多功能坝)。

最近，由于人口增长和经济发展对水资源要求增加，需要建设一些大坝蓄水。在美国，平均每人每天要消耗 137 加仑的水，由此把水导入自来水厂。这个数字包括社区中居民、商业和工业用水。在城镇有许多工业用水大户，每人用水要求会更多，例如，需要 65 000 加仑水制成 1 吨钢，10 加仑的水方可提炼 1 加仑汽油。

从人类利益考虑建设大坝是利用和控制水资源的关键手段，时常也存在一些问题，由于用坝拦截了河流，妨碍了船只航运和鱼的迁移。在河流船只渠道通航处，坝上要建

船闸。鱼的迁移也很重要，像船闸一样要有鱼闸。对于有价值的鱼类也应建鱼闸，如鲑鱼可能在坝附近游嬉。鱼会进入最低的、向上的一系列水池，从一个水池进入到另一个水池直到他们进入水库。

在建设大坝和相关的附属设施中一些先进的技术是很需要的，从破坏角度考虑它们将是经济的、有益的和安全的。在现场勘测地形地貌初期阶段，航空照片是有用的。关于水文地质、地质、水力和其他学科的专业知识可用于解决一些复杂问题，即在分析基础岩石和土(大坝现场河床所揭示的岩石和土)，设计和建设大坝和相关的设施中所遇到的问题。选择在大坝建设中所用到的每种材料，如土、岩石或混凝土，应能在特定的现场以最为经济的方式得到所希望的成果。对每种材料进行细心的研究和分析得以保证大坝不透水、有着足够的重量和强度抵抗大坝迎水面所受的水库水压力。在高坝中，这种压力非常巨大，例如 Hoover 坝基水压力达到 310 MPa。

Unit 15

Text

Concrete Gravity Dams on Rock Foundations

The designer of any dam must make basic assumptions regarding site conditions and their effects on the proposed structure. Site investigations provide the engineer with much of the information to evaluate these assumptions, the bases for safe dam design. Some important assumptions for small dam design involve uplift pressure, seepage control measures, channel degradation and downstream toe erosion, foundation conditions, and quality of construction. Additional assumptions should involve silt loads, ice pressures, earthquake accelerations, and wave forces.

1 Safety Factors

Safety factors should be considered in the light of economic conditions. Large safety factors result in a more costly structure; however, low safety factors may result in failure, which could also lead to high cost. Proper safety factors result only from an adequate determination of sliding, overturning, and overstressing forces within and acting on the dam.

1.1 Overturning

Ordinarily, the safety factor against overturning is between 2 and 3. In smaller dams it is often larger. If the computed safety factor falls below 2, the section of the dam should be modified to increase the safety margin. A gravity dam rarely fails from overturning since any tendency to overturn provides greater opportunity for a sliding force to create the failure. The safety factor against overturning is the ration of the righting moment to the overturning moment about the toe of the dam. This can be expressed as

$$FS_{O} = \frac{W_c \times l_1 + W_w \times l_2}{P \times l_3 + U \times l_4} \tag{15.1}$$

where W_c is force due to weight of concrete; W_w is force due to weight of water on inclined surfaces; P is force of water acting to displace dam downstream; U is uplift force; l is length of moment arm for respective forces.

Also, if the uplift pressure at the upstream face exceeds the vertical stress at any horizontal section without uplift, the uplift forces greatly increase the tendency for overturning about the downstream toe at that assumed horizontal plane. The dam may still be considered safe if the tension stresses developed are less than the allowable stresses in the concrete and in the

foundation material. This assumption is based on good workmanship and development of a tensile strength within the structure on all horizontal planes.

1.2 Sliding

Three approaches are used by engineers in evaluating the safety of a dam from being displaced downstream. Each has merit and generally involves the same relationship of forces. Although the computed values are safe, they are considerably different. The three approaches are: ①a safe sliding factor; ②a safety factor; ③a shear-friction safety factor. Clear distinction must be made among these three approaches. The primary purpose of each is to obtain a safe coefficient that when exceeded would put the dam in jeopardy of being pushed downstream.

The sliding factor of a gravity dam with a horizontal base equals the tangent of the angle between the perpendicular to the base and the resultant foundation reaction. The sliding factor for small dams is computed by taking the ratio of the summation of horizontal forces $\sum P$, to the summation of vertical forces $\sum Y$, including the uplift U, or

$$f = \tan\theta = \frac{\sum P}{\sum W - U} \tag{15.2}$$

If f computed in this manner is equal to or less than the static friction coefficient f', the dam is considered safe. A unit width of 1 ft. is assumed for these calculations. Safe values for the sliding factor coefficient are given in Table 15.1 for various foundation materials.

Table 15.1 Allowable sliding factors for various foundation conditions

Material	Safe sliding factor, f	Suggested minimum factor of safety, f_s	Shear sliding factor, SSF
Concrete on concrete	0.65~0.8	1~1.5	4
Concrete on sound rock, clean and irregular surface	0.8	1~1.5	4
Concrete on rock, some laminations	0.7	1~1.5	4
Concrete on gravel and coarse sands	0.4	2.5	—
Concrete on sand	0.3	2.5	—
Concrete on shale	0.3	2.5	—
Concrete on silt and clay	*	2.5*	—

The factor of safety, f_s, against sliding is defined as the ratio of the coefficient of static friction f', to the tangent of the angle between a perpendicular to the base and the direct foundation reaction, expressed as

$$f_s = \frac{f'}{\tan\theta} = \frac{f'(\sum W - U)}{\sum P} \tag{15.3}$$

This approach also assumes shear forces as added safety measure. The safety factor against sliding is usually between 1 and 1.5 for gravity dams on rock utilizing a conservative cross-section. The inclusion of uplift and seismic forces in the calculations may reduce the

safety factor to about unity. These values are for safety against sliding on a horizontal plane; if the foundation slopes downstream, the safety factors against sliding on the plane of the base are correspondingly reduced. Designers often use concrete placed into cutoffs or rock foundations to decrease the sliding tendency of the dam.

Another approach, favored by many engineers, includes the evaluation of shear into the safety factor. The shear-friction relationship is

$$S_F = \frac{f'(\sum W - U) + b\sigma}{\sum P} \tag{15.4}$$

where b is base length at plane of shear being studied; σ is allowable working shear stress of material or materials at plane of shear.

Safety factors computed in this manner should approach values used in normal structural computations. Static friction values often assumed for concrete moving rock or concrete on concrete surfaces varies from 0.65 to 0.75. The working shear stress σ of concrete is related to the compressive strength of concrete. The unit shearing strength of concrete is about one-fifth of the compression breaking stress from standard cylinders. This indicates a strength of 2.76 to 5.51 MPa for concrete in dams. It also provides a safety factor of 4 if the unit working stresses used in computations are 0.69 to 1.38 MPa. Greater working stresses are not recommended unless the concrete for the smaller dams is actually pretested.

New Words and Expressions

1. degradation [ˌdegrəˈdeiʃən] *n.* 降低
   channel~ 河槽刷深
2. margin [ˈmɑːdʒin] *n.* 余量(额，地)，页边
3. moment [ˈməumənt] *n.* 力矩，动量
   overturning ~ 倾覆力矩
   ~ arm 力臂
4. measure [ˈmeʒə] *n.* 量度，测量
5. cross-section 横断面
6. shear [ʃiə] *v, n.* 剪切，剪(应变)
7. stress [stres] *n.* 应力
   tension ~ 拉应力
   breaking ~ 破坏应力
8. pretest [ˈpriːtest] *n.* 事先试验，预先检验
9. joint [dʒɔint] *n, vt.* 节理，接缝，连接
10. sound [saund] *a.* 坚固的，合理的
11. allowable stress 允许应力
12. workmanship [ˈwəːkmənʃip] *n.* 工艺，技巧
13. tensile [ˈtensail] *a.* 拉[张]力的
14. factor [ˈfæktə] *n.* 系数，因素
15. friction [ˈfrikʃən] *n.* 摩擦，摩阻
16. static [ˈstætik] *a.* 静止的，固定的
17. coefficient [kəuiˈfiʃənt] *n.* 系数，折算率
18. mix [miks] *n.* 混合料，配合比
19. weighted [ˈweitid] *a.* 加权的，权重的
20. creep [kriːp] *n.* 蠕变，滞缓
21. ratio [ˈreiʃiəu] *n.* 比率，系数
22. load-bearing value 承载值
23. lamination [ˌlæmiˈneiʃən] *n.* 层压(成型)，纹理
24. shale [ʃeil] *n.*(油)页岩
25. boulder [ˈbəuldə] *n.* 漂石，圆卵石
26. cobble [ˈkɔbl] *n.* 鹅卵石，中砾石
27. hardpan [ˈhɑːdpæn] *n.* 硬土层
28. cylinder [ˈsilində] *n.* 圆柱，圆筒，柱面
29. in the light of 根据，按照，鉴于

30. confer with 与……商量
31. be defined as (被)定义为
32. be expressed as (被)表达为

岩基上的混凝土重力坝

设计人员在设计任何大坝时，都必须对场地条件和场地对建筑物影响作出一些基本论证。场地调查为工程师提供更多信息来评估这些论证，也为大坝安全设计提供许多依据。小坝设计的重要论证包括扬压力、渗透控制措施、河床冲刷和下游坝趾的侵蚀、地基条件和施工质量。其他论证包括泥沙压力、冰压力、地震加速度和波浪力。

一、安全系数

安全系数视经济条件而定。安全系数大，导致建筑物费用高；然而，安全系数低可能引起破坏，也会使费用高。合适的安全系数与滑动、倾覆和作用在坝内和坝上的力有关。

(一)倾覆

通常来说，抗倾覆安全系数在 2~3 之间。坝越小，这个值越大。如果计算的安全系数小于 2，应修改该坝断面，提高安全度。重力坝很少因倾覆而破坏，因为任何倾覆驱动对滑动破坏来说有了更大机会。抗倾覆安全系数定义为坝趾处右旋力矩和抗倾覆力矩之比。公式表示如下

$$FS_0 = \frac{W_c \times l_1 + W_w \times l_2}{P \times l_3 + U \times l_4} \tag{15.1}$$

式中：W_c 为混凝土质量引起的重力；W_w 为倾斜坝坡面上水的质量引起的重力；P 为水对坝向下游的推力；U 为扬压力；l 为不同作用力力臂。

此外，如果上游面的扬压力超过任一水平断面上不计扬压力的垂直力，则扬压力将使坝趾处所假定的水平面上倾覆趋势大大增加。如果在混凝土内和地基内所引起的拉应力小于允许值，则该坝仍可以认为是安全的。这个假定是基于施工工艺良好，同时建筑物内所有水平面都有抗拉强度。

(二)滑动

工程师评价大坝向下游移动的安全性采用三种方法。每一种都有优点且一般考虑力与力之间有相同关系。尽管计算值是安全的，但是差异显著。三种方法是：①抗滑安全系数；②安全系数；③剪–摩安全系数。必须将这三种方法区别清楚。每种方法的基本目的都是得到一个安全系数，当超过该值时，坝就有向下游滑动的危险。

具有水平地基面的重力坝的安全系数等于地基垂直方向与总的地基反力的方向夹角的正切值。对于小型坝来说，滑动安全系数取水平力总和 $\sum P$ 与垂直力总和 $\sum Y$ (包括扬压力 U)的比值

$$f = \tan\theta = \frac{\sum P}{\sum W - U} \tag{15.2}$$

如果用这种办法计算的安全系数 f 值小于或等于静摩擦力系数 f'，大坝认为是安全的。计算时取单宽即一英尺。表 15.1 给出了各种地基抗滑安全系数值。

抗滑安全系数f_s的定义是静摩擦力系数f'与基础的垂直方向和地基直接反力方向夹角正切的比值，即

$$f_s = \frac{f'}{\tan\theta} = \frac{f'(\sum W - U)}{\sum P} \tag{15.3}$$

这个方法也假定对剪力要增加安全设施。对于建立在岩石上的重力坝在保守的横断面上，抗滑安全系数一般在 1~1.5 之间。计算中计入扬压力和地震力后，安全系数可降至 1 左右。这些数值都是指水平面上的抗滑安全系数；如果地基倾向下游，则基础面上的抗滑安全系数会相应降低。设计人员利用切槽或岩基上浇筑混凝土的办法来减少坝滑动的趋势。

被多数工程师所称赞的另一种方法是在安全系数中包括剪力。剪-摩关系式为

$$S_F = \frac{f'(\sum W - U) + b\sigma}{\sum P} \tag{15.4}$$

式中：b 为所研究剪切面上的基础宽度；σ 为材料或剪切面材料的允许工作剪应力。

这种方法得到的安全系数应该接近正常结构计算中的值。对混凝土和岩石间或混凝土与混凝土间，静摩擦系数一般假定在 0.65~0.75 间。混凝土的工作剪切力 σ 和混凝土的抗压强度有关。混凝土的单位剪切强度为标准圆柱体试件压缩破坏强度的 1/5。对坝体混凝土来说，强度指标为 2.76~5.51 MPa。如果在计算中采用的单位工作应力为 0.69~1.38 MPa，则安全系数为 4。除非对较小坝来说混凝土事先作过实验，否则不宜采用更大的工作应力。

Reading Material

Concrete Gravity Dams on Soft Foundations

Dams on soft foundation materials must be safe against the same forces as dams on good rock foundations. In addition, the designer must consider the effects of seepage, piping underneath the dam, and subsidence or consolidation of the foundation materials.

From an engineering viewpoint, the water movement below or through a dam is not objectionable if the flow does not exceed safe limits of design. However, the total flow may be large enough to make it economically desirable to seal off the permeable zone. Water that passes under the dam is lost for that project; however, stream flow may be sufficient for the designer to reduce construction costs by permitting some flow within safe limits. These limits may be summarized for pervious dam foundations as:

(1)Limit percolation velocities and pressures in the foundation material so they do not move the soil particles to cause piping, scouring of the foundation or mass flow of the material.

(2)Limit the seepage uplift pressure under the foundation so that no undesirable overturning moment and no sliding on the foundation occur.

1 Flow in Porous Material

Flow through porous material may be estimated by using the Darcy equation

$$Q = KiA \tag{15.5}$$

where Q is discharge in a given unit of time; K is coefficient of permeability for the foundation, i.e., discharge through a unit area at unit hydraulic gradient; i is hydraulic gradient, difference in head divided by length of path, h/L; A is gross area of foundation through which flow takes place.

The coefficient, K, is determined by several methods. The most satisfactory and economical for small dams is the pumping in test. In this test, water is pumped into a drill hole or test pit; the seepage rate is observed under a given water head.

The pumping-out test is relatively expensive and results are more difficult to interpret. This test measures gross permeability by pumping water from a well hole at a constant rate and measuring the draw-down of the water table in observation wells at various distances from the pumped well.

The dye test relates the rate of flow of a dye or electrolyte from the point of injection to an observation well. This test requires several trials since the assumed direction of flow for the dye may or may not be along the underground flow paths. Several trials (with observation well relocations) may be needed to adequately estimate permeability.

2 Seepage Forces

The magnitude of the seepage forces through the foundation and at the downstream toe of the structure depends on the rate of head loss of the moving water. Impervious soils are not as susceptible to piping because they offer greater resistance to flow, and the reservoir head is largely dissipated by friction. On the other hand, pervious soils (and stratified or fractured rock) may permit substantial flow movement at the downstream toe of the dam without much loss of head due to friction. In such instances, the designs must be investigated to ensure against blowouts.

Another type of failure is due to internal erosion from springs near the downstream toe. It proceeds upstream along the base of the dam, the walls of a conduit, a bedding plane, or other type of weakened zone. This type of failure is due to subsurface erosion.

The magnitude and distribution of seepage forces may be determined by a flow-net analysis. A flow net is a graphic representation of percolation paths and lines of equal potential (pressure plus elevation above a datum) in subsurface flow. The flow net is limited in the analysis of problems of stratified flow or problems of subsurface spring erosion failures. Further, drawing an accurate flow net requires considerable experience, particularly when cutoff walls are used and non-homogeneous soils make up the foundation.

Incipient piping occurs when the pressure exerted on the soil by moving water exceeds the resistive force offered by the soil. The seepage force, P_f exerted on the soil by the water,

equal the unit weight of water, W, times the hydraulic gradient, i, which acts on a unit volume of soil. If the soil is homogeneous, the force acts uniformly on the whole soil mass. The critical point for incipient piping is at the downstream of the dam.

Darcy's laws permits a theoretical basis for providing an adequate length of water travel beneath a dam. The relationship for discharge may be stated as

$$Q=KiA=C_t HA/L \tag{15.6}$$

where Q is discharge, cfs; H is head (reservoir depth), ft; L is length of path, ft; C_t is coefficient dependent on the material.

From a continuity, $Q=AV$; hence, $L=C_t H/V$. (15.7)

For a given material, there is a maximum velocity, V, at which water can emerge from below the dam without causing failure by carrying away the foundation material. The length of travel is established by the weighted line of creep, as proposed by Lane. Lane's procedure places greater emphasis on vertical travel than on the horizontal paths (in contrast with Bligh's equal weight values). In computing the line of creep for Lane's procedure, the horizontal distances of flow are taken as one-third the value of vertical distances. Vertical distances, including 45-deg slopes, are taken as full-length values for creep distance.

One point not fully evaluated in either procedure concerns incipient piping below the dam. Both authors recognize the increased hydraulic gradient at the downstream toe by requiring that cutoffs and drainage filters be properly placed at the toe. A safe pressure gradient must be ensured at this critical point in design. The more rapid the upward reduction in pressure, the less stable the material, until a critical value the material actually moves or floats out. This critical value is expressed as

$$H/L=(S-1)(1-P) \tag{15.8}$$

where S is specific gravity of material; P is percentage of voids in material expressed as a decimal.

Safety from toe floatation can best be accomplished by providing a cutoff wall and inverted sand-drain filter upstream of the wall, with pipe drains carrying the water to the surface. These effectively reduce uplift pressures and eliminate piping. This type of cutoff should be made in conjunction with an upstream cutoff wall that reduces uplift forces.

The electric analogy is an economical, rapid method to analyze cutoff walls and dam foundation condition. This method makes use of Darcy's law to develop a flow net that is analyzed for the various forces and critical conditions of flow. Flow nets can be constructed by a mathematical method, graphic method, or model experiments.

New Words and Expressions

1. subsidence ['sʌbsidəns] *n.* 下沉，沉降
2. consolidation [kən,sɔli'deiʃən] *n.* 固结
3. resistance [ri'zistəns] *n.* 阻力，抗力
4. percolation [,pəːkə'leiʃən] *n.* 渗透
   percolation path 渗径
5. alluvial [ə'luːvjəl] *a.* 冲积的，冲积土

6. scour ['skauə] *v.* 冲刷，疏浚
7. Darcy equation 达西公式
8. mass flow 质量流(量)
9. hydraulic gradient 水力梯度
10.gross [grəus] *n* 总(毛)重，全体，总数
11. media ['mi:djə] *n.* (medium 复数)介质
12. blowout ['bləu'aut] *n.* 井喷
13. bedding ['bediŋ] *n.* 基床
    bedding plane 岩层面
14. weakened zone 软弱带
15. seepage force 渗流力
16. flow line 流线
17. incipient [in'sipiənt] *a.* 原始的，最初的 ~ piping 初期管涌
18. cfs (cubic feet per second) 立方英尺每秒
19. specific [spi'sifik] *a.* 具体的，单位的
20. void [vɔid] *n.* 孔隙，孔率，空洞
21. drill [dril] *n.* 钻孔，凿片，训练
22. pumping-out test 抽水试验
23. drawdown ['drɔ:daun] *n.* 下降，降落
24. dye [dai] *v.* 染色，着色
25. electrolyte [i'lektrəulait] *n.* 电解质
26. injection [in'dʒekʃən] *n.* 注射，喷射
27. stratified ['strætifaid] *a.* 分层的，成层的 ~ flow 层流
28. homogeneous [,hɔməu'dʒi:njəs] *a.* 均质的
29. nonhomogeneous ['nɔn,hɔmə'dʒi:njəs] *a.* 非均质的
30. flow net 流网
31. line of equal potential 等势线
32. datum ['deitəm] *n.* 数据，基准(点，面)
33. floatation [fləu'teiʃən] *n.* 漂浮，浮力
34. invert [in'və:t] *v.* 颠倒，倒转，使反向
    inverted sand-drain filter 砂质排水反滤层
35. analogy [ə'nælədʒi] *n.* 类比，类似
36. graphic ['græfik] *a.* 图解的，绘图的
37. arid ['ærid] *a.* 干燥
38.pf=perfect ['pə:fikt] *a.* 理想的

阅读材料

软基上的混凝土重力坝

在相同受力条件下，位于软基上的坝与完整岩石为基础的坝一样必须是安全的。除此之外，设计者还必须考虑渗透效应、坝下管涌、地基的沉降或固结。

从工程观点出发，如果水渗流没有超过设计安全极限，通过坝下或坝身水渗流是允许的。然而，如果总的渗流量很大，从经济上考虑对渗透带进行封堵是值得的。坝下渗漏对工程来说是损失；然而，在安全范围内允许一定渗漏可以减少施工费用。对渗透坝基来说这些限制总结如下：

(1)在基础材料中限定渗漏速度和压力不致引起土颗粒移动形成管涌、冲刷地基或块体流动。

(2)限定基础下的渗透扬压力，这样使基础不发生倾覆力矩，甚至滑动。

一、孔隙介质中的水流

利用达西定律可以估计孔隙介质的流量

$$Q = KiA \tag{15.5}$$

式中：Q 为单位时间的排泄量；K 为地基的渗透系数，即在单位水力梯度下单位面积的排泄量；i 为水力梯度，水头差除以渗透长度，h/L；A 为通过渗透的地基横断面面积。

系数 K 可通过几种方法确定。对于小型坝的建设最为满意且经济的方法是抽水试验。在该试验中，水被抽到钻孔或试验坑中；在给定的水头下观察渗透率。

抽水试验相对费用高，成果解释更困难。这种试验是在井孔中以不变的速率进行抽水来粗略地估计岩石渗透性，并从离抽水井不同距离上的观测井量测水位下降情况。

染色试验与染色水流速度有关或与从颜色注入点到观测井的电解质有关。这种试验需要多做几次，因为染色剂假定的方向有可能会或也有可能不会沿着地下水流动方向。为了充分地估计渗透性，需多次试验才行(观测井位置会有变化)。

二、渗透力

通过基础和下游坝趾渗透力的大小依赖于流动水的水头损失率。非渗透土对管涌是不敏感的，因为它们存在大的抗渗透性，水库水头由于摩擦作用而大大消耗。另一方面，在下游坝趾处渗漏土(成层或碎裂岩石)可允许发生大的渗流，因为摩擦引起水头损失极小。在这种情况下，研究设计方案，保证坝趾不发生喷水。

另一种破坏类型是由于下游坝趾附近泉的侵蚀引起。它会发生在上游坝基、管道侧壁、岩层面或软弱带。这种破坏是由于地下的侵蚀作用发生的。

渗透力的大小和分布通过流网分析来确定。流网是地下水流渗透路径和等势线交织而成(压力+基准值高程)。流网在分析层流或地下泉侵蚀破坏问题中存在局限性。更进一步说，绘制精确的流网需要丰富的经验，尤其设有截渗墙和地基为非均质土使问题更为棘手。

当地下水运动施压于土体的压力超过土体自身强度时产生初期管涌。由理想水体施加在土体上的渗透压力 P_f 等于水的重量 W 与作用在单位土体上的水力梯度 i 的乘积。如果土体是均匀的，在土体上的作用力也是均匀的。初始管涌的临界点在大坝下游坝趾处发生。

当地下水在坝下渗径足够长可采用达西定律。对泄水量来说，其关系式为：

$$Q = KiA = C_t HA / L \tag{15.6}$$

式中：Q 为泄水量，立方英尺/秒；H 为水头(水库深)，英尺；L 为渗径长度，英尺；C_t 为与材料有关的系数。

对于连续介质，$Q = AV$；因此，

$$L = C_t H / V \tag{15.7}$$

对于给定材料，当水在坝下渗出时，流速 V 达到最大值，坝基材料被带走但没有引起破坏。渗透长度由 Lane 建议的蠕变权重流线来确定。Lane 的方法假定竖直渗透路径要大于水平渗透路径(而 Bligh 用等权)。用 Lane 方法计算蠕变流线时，流线的水平距离取垂直距离的 1/3。竖直距离(包括 45 度挖坡)取蠕变流线距离整个长度。

涉及坝下早期管涌的任何一种方法所作出的评价都不充分。两者认识到在下游坝趾处要增加水力梯度则需要在该处适当布置截渗墙或排水滤料。在设计中临界点安全压力

梯度必须得到保证。向上压力减少越快，材料越不稳定，直到临界值，材料实际上已移动或流出。该临界值为

$$H/L=(S-1)(1-P) \tag{15.8}$$

式中：S 为材料的比重；P 为孔隙率(%)。

从坝趾浮动安全考虑最好要设截渗墙并在墙上游面铺设砂反滤料且用排水管把水抽到地表。这些方法可有效地减少扬压力和消除管涌。这种类型截渗墙应当和上游减少扬压力的截渗墙相接。

用电模拟分析截渗墙和坝基条件是一种经济和迅速的方法。这种方法采用达西定律来绘制流网用于分析水流的各种力和临界条件。流网可通过数学方法、图解方法或模拟试验来绘制。

Unit 16

Text

Shotcrete Support

The use of shotcrete for the support of underground excavations was pioneered by the civil engineering industry. Reviews of the development of shotcrete technology have been presented by Rose (1985), Morgan (1992) and Franzén (1992). Rabcewicz (1969) was largely responsible for the introduction of the use of shotcrete for tunnel support in the 1930s, and for the development of the New Austrian Tunneling Method for excavating in weak ground.

In recent years, the mining industry has become a major user of shotcrete for underground support. It can be expected to make its own contributions to this field as it has in other areas of underground support. The simultaneous working of multiple headings, difficulty of access and unusual loading conditions are some of the problems which are peculiar to underground mining and which require new and innovative applications of shotcrete technology.

An important area of shotcrete application in underground mining is in the support of "permanent" openings such as ramps, haulages, shaft stations and crusher chambers. Rehabilitation of conventional rockbolt and mesh support can be very disruptive and expensive. Increasing numbers of these excavations are being shotcreted immediately after excavation. The incorporation of steel fiber reinforcement into the shotcrete is an important factor in this escalating use, since it minimizes the labor intensive process of mesh installation.

Recent trials and observations suggest that shotcrete can provide effective support in mild rockburst conditions. While the results from these studies are still too limited to permit definite conclusions to be drawn, the indications are encouraging enough that more serious attention will probably be paid to this application in the future.

Shotcrete is the generic name for cement, sand and fine aggregate concretes which are applied pneumatically and compacted dynamically under high velocity.

Dry mix shotcrete As illustrated in Figure 16.1, the dry shotcrete components, which may be slightly pre-dampened to reduce dust, are fed into a hopper with continuous agitation. Compressed air is introduced through a rotating barrel or feed bowl to convey the materials in a continuous stream through the delivery hose. Water is added to the mix at the nozzle. Gunite, a proprietary name for dry-sprayed mortar used in the early 1900's, has fallen into disuse in favour of the more general term shotcrete.

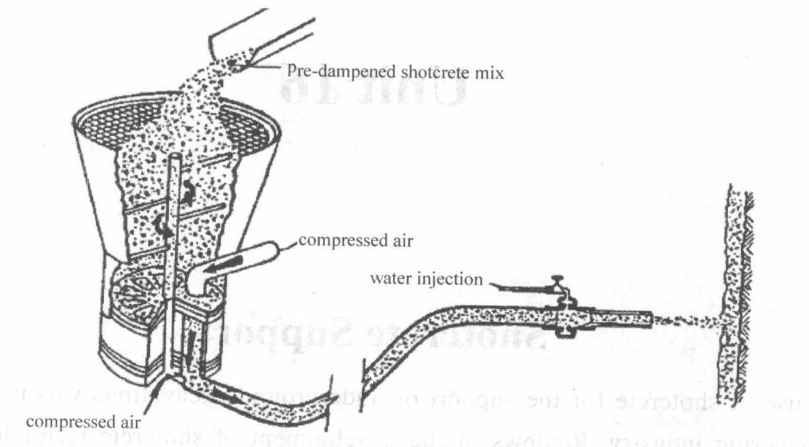


Figure 16.1 Simplified sketch of a typical dry mix shotcrete system(After Mahar et al, 1975)

Wet mix shotcrete In this case, the shotcrete components and the water are mixed (usually in a truck mounted mixer) before delivery into a positive displacement pumping unit, which then delivers the mix hydraulically to the nozzle where air is added to project the material onto the rock surface(Fig. 16.2).

The final product of either the dry or wet shotcrete process is very similar. The dry mix system tends to be more widely used in mining, because of inaccessibility for large transit mix trucks and because it generally uses smaller and more compact equipment. This can be moved around relatively easily in an underground mine environment. The wet mix system is ideal for high production applications in mining and civil engineering, where a deep shaft or long tunnel is being driven and where access allows the application equipment and delivery trucks to operate on a more or less continuous basis. Decisions to use the dry or wet mix shotcrete process are usually made on a site-by-site basis.

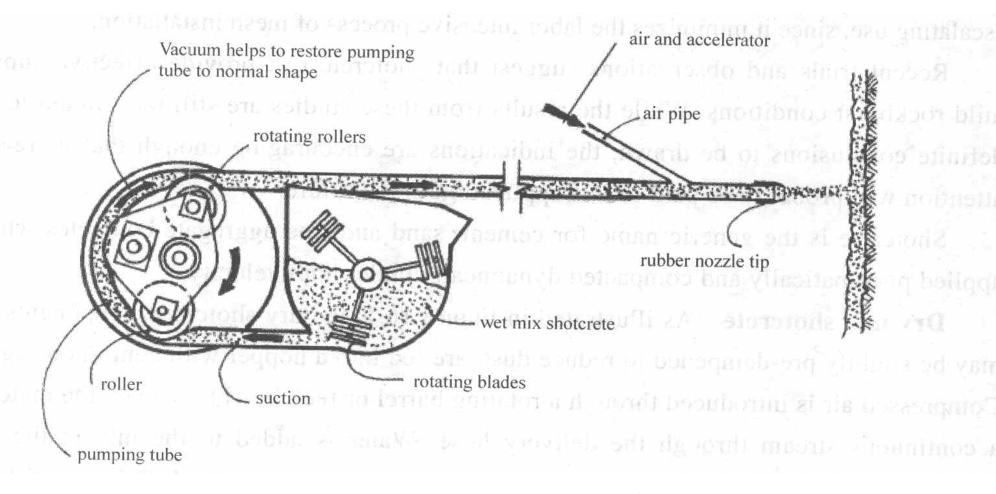


Figure 16.2 One typical type of wet mix shotcrete machine (After Mahar et al, 1975)

New Words and Expressions

1. shotcrete *n.* 喷射混凝土
2. pioneer [ˌpaiəˈniə] *v.* 为……开路，开拓
3. the New Austrian Tunneling Method(NATM) 新奥地利隧洞施工法
4. simultaneous [ˌsiməlˈteinjəs] *a.* 同时的，同时发生的
5. ramp [ræmp] *n.* 斜坡，坡道
6. haulage [ˈhɔːlidʒ] *n.* 运输，巷道
7. shaft [ʃɑːft] *n.* 竖井，坑道
8. chamber [ˈtʃeimbə] *n.* 室
9. rehabilitation [ˈriː(h)əˌbiliˈteiʃən] *n.* 恢复
10. escalate [ˈeskəleit] *n.* 逐步升级，逐步升高
11. rockburst *n.* 岩爆
12. generic [dʒiˈnerik] *a.* 一般的，普通的
13. fine aggregate 细骨料
14. pneumatically [nju(ː)ˈmætikli] *adv.* 有空气作用地
15. hopper [ˈhɔpə] *n.* 漏斗
16. agitation [ædʒiˈteiʃən] *n.* 搅动
17. nozzle [ˈnɔzl] *n.* 管口，喷嘴
18. gunite [ˈgʌnait] *n.* 压力喷浆
19. proprietary [prəˈpraiətəri] *n.* 私人拥有
20. mortar [ˈmɔːtə] *n.* 灰浆
21. vacuum [ˈvækjuəm] *n.* 真空
22. suction [ˈsʌkʃən] *n.* 吸力，吸气
23. hydraulically [haiˈdrɔːlikli] *adv.* 水力学地
24. project [ˈprɔdʒekt] *v.* 发射
25. inaccessibility [ˌinækˌsesəˈbiliti] *n.* 不易接近，难达到

喷混凝土支护

土木工程行业率先将喷混凝土用于地下工程的支护。Rose(1985)等对喷混凝土技术的发展提出了很多观点。20 世纪 30 年代喷混凝土技术在隧洞支护方面的应用以及新奥法(The New Austrian Tunnelling Method)在软弱岩石隧洞掘进的应用主要归功于Rabcewicz(1969)。

近年来，采矿业成为喷混凝土技术运用于地下支护的主要用户。采矿业在喷混凝土支护方面的贡献与它对地下工程支护的贡献相类似。多个导洞同时开挖、洞室进出口交通困难和特殊的荷载条件是地下采矿业特有的问题，这些问题要求采用新的和有创造性的喷混凝土技术。

在地下采矿业中，喷混凝土应用的一个重要方面是对斜坡道、运输巷道、井站和破碎机室这类永久工程的支护。常规岩石锚杆和挂网支护的维护可能是非常昂贵的。越来越多的这类永久工程在开挖后立即喷混凝土。把钢纤维加入喷混凝土中是使这一方法的应用得到推广的重要因素，因为它减少了挂网安装中的劳动力密集型的工作。

最近的试验和观察表明，在中等岩爆条件下，喷混凝土仍可以提供有效的支护。然而，这些研究结果仍然十分有限，尚不能得出明确的结论，有迹象表明将来可能会有更多的注意力集中在喷混凝土的应用方面。

喷混凝土是采用高压喷射的、在高速情况下被冲击密实的水泥、砂和细骨料混凝土的总称。

干混法喷混凝土　如图 16.1 所示，把混凝土材料略微加水减少灰尘，在不断搅拌的

情况下送入漏斗。压缩空气通过旋转桶或加料槽在传输软管的连续流中输送喷混凝土。水在喷嘴处与材料混合。喷浆，这个在20世纪早期用于喷砂浆的专用名词已经被废弃，而改为更通用的名称“喷混凝土”。

湿混法喷混凝土　在这一方法中，把喷混凝土材料送入泵压设备前，喷混凝土材料和水已混合(通常在卡车上装有搅拌器)，然后利用液压把混合料传到喷嘴，加入空气以利于把这些混合物喷到岩石表面上(见图 16.2)。

干喷法和湿喷法最终情况非常相似。干喷法在采矿业的使用更为广泛，因为大型运输搅拌车不易通行，采矿行业一般使用小型和简便的设备。这些设备在地下工程中移动方便。湿喷系统对于采矿业和土木工程行业的大规模生产非常理想，在这些地方，大型竖井或长隧道已经开挖，交通洞允许喷施设备和运送卡车用连续的方式作业。使用干喷法或湿喷法的决策通常取决于现场的情况。

Reading Material

Steel Fibre Reinforced Micro Silica Shotcrete

Of the many developments in shotcrete technology in recent years, two of the most significant were the introduction of silica fume, used as a cementitious admixture, and steel fibre reinforcement.

Silica fume or micro silica is a by-product of the ferro silicon metal industry and is an extremely fine pozzolan. Pozzolans are cementitious materials which react with the calcium hydroxide produced during cement hydration. Silica fume, added in quantities of 8% to 13% by weight of cement, can allow shotcrete to achieve compressive strengths which are double or triple the value of plain shotcrete mixes. The result is an extremely strong, impermeable and durable shotcrete. Other benefits include reduced rebound, improved flexural strength, improved bond with the rock mass and the ability to place layers of up to 200 mm thick in a single pass because of the shotcrete's "stickiness" . However, when using wet mix shotcrete, this stickiness decreases the workability of the material and superplaticizers are required to restore this workability.

Steel fiber reinforced shotcrete was introduced in the 1970s and has since gained world-wide acceptance as a replacement for traditional wire mesh reinforced plain shotcrete. The main role that reinforcement plays in shotcrete is to impart ductility to an otherwise brittle material. As pointed out earlier, rock support is only called upon to carry significant loads once the rock surrounding an underground excavation deforms. This means that unevenly distributed non-elastic deformations of significant magnitude may overload and lead to failure of the support system, unless that system has sufficient ductility to accommodate these deformations.

Typical steel fibre reinforced, silica fume shotcrete mix designs are summarised in

Table 16.1. These mixes can be used as a starting point when embarking on a shotcrete programme, but it may be necessary to seek expert assistance to "fine tune" the mix designs to suit site specific requirements. For many dry mix applications, it may be advantageous to purchase pre-mixed shotcrete in bags of up to 1 500 kg capacity, as illustrated in Figure 16.3.

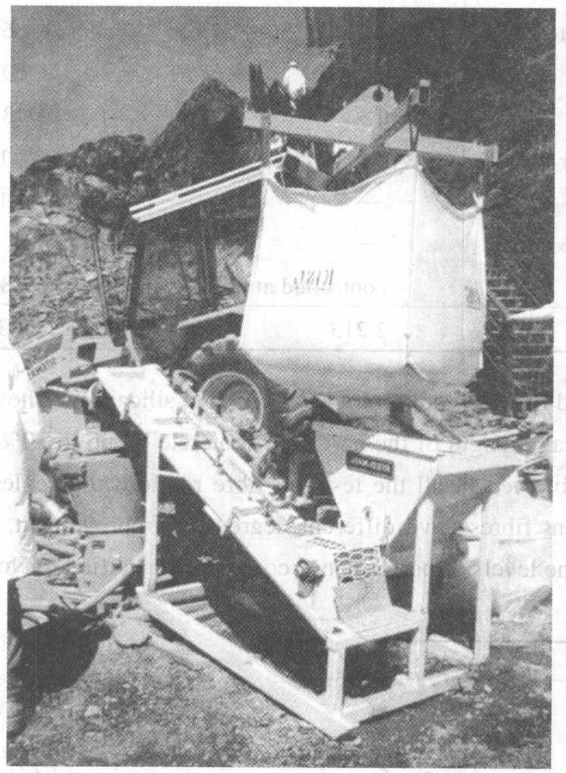


Figure 16.3 Bagged pre-mixed dry shotcrete components being delivered into a hopper feeding a screw conveyor, fitted with a predampener, which discharges into the hopper of a shotcrete machine

Figure 16.4 shows the steel fiber types which are currently available on the north American market. In addition to their use in shotcrete, these fibers are also widely used in concrete floor slabs for buildings, in airport runways and in similar concrete applications.

Wood et al (1993) have reported the results of a comprehensive comparative study in which all of the fibres shown in Figure 16.4 were used to reinforce shotcrete samples, which were then subjected to a range of tests. Plain and fibre reinforced silica fume shotcrete samples were prepared by shooting onto vertical panels, using both wet and dry mix processes. The fibre reinforced samples all contained the same steel fibre dosage of 60 kg/m^3(Table 16.1). All the samples were cured under controlled relative humidity conditions and all were tested seven days after shooting.

Table 16.1 Typical steel fibre reinforced silica fume shotcrete mix designs (After Wood, 1992)

Components	Dry mix		Wet mix	
	kg/m^3	% dry materials	kg/m^3	% wet materials
Cement	420	19.0	420	18.1
Silica fume additive	50	2.2	40	1.7
Blended aggregate	1 670	75.5	1 600	68.9
Steel fibres	60	2.7	60	2.6
Accelerator	13	0.6	13	0.6
Superplasticizer	—	—	6 litres	0.3
Water reducer	—	—	2 litres	0.1
Air entraining admixture	—	—	if required	
Water	controlled at nozzle		180	7.7
Total	2 213	100	2 321	100

These tests showed that the addition of steel fibres to silica fume shotcrete enhances both the compressive and flexural strength of the hardened shotcrete by up to 20%. A significant increase in ductility was also obtained in all the tests on fibre reinforced samples, compared with plain samples. While different fibres gave different degrees of improvement, all of the fibres tested were found to exceed the levels of performance commonly specified in North America.

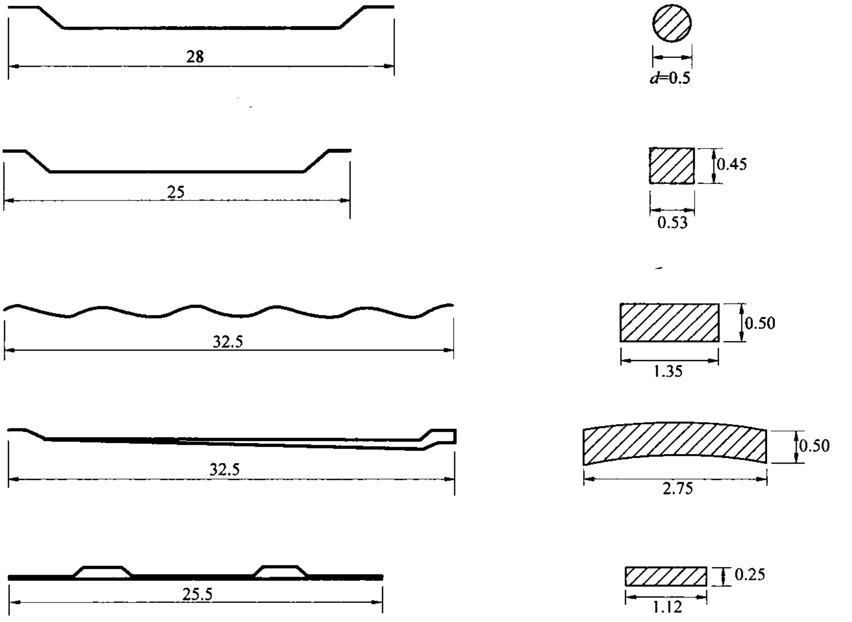


Figure 16.4 Steel fibre types available on the north American market(After Wood et al, 1993)
(Note: all dimensions are in mm)

New Words and Expressions

1. silica ['silikə] *n.* 硅，二氧化硅
2. fume [fju:m] *n.* 烟尘，气体
3. cementitious [ˌsimen'tiʃiəs] *a.* 似水泥的
4. admixture [əd'mikstʃə] *n.* 混合，混合物
5. by-product 副产品
6. fibre ['faibə] *n.* 纤维
7. pozzolan ['pɔtsəulɑ:n] *n.* 火山灰
8. calcium ['kælsiəm] *n.* 钙
9. hydroxide [hai'drɔksaid] *n.* 氢氧化物
10. hydration [hai'dreiʃən] *n.* 水合作用
11. triple ['tripl] *n.* 三倍
12. rebound [ri'baund] *v.* 回弹，反弹
13. superplasticizer *n.* 超可塑剂
14. impart [im'pɑ:t] *v.* 赋予，告知
15. ductility [dʌk'tiliti] *n.* 和易性
16. brittle ['britl] *a.* 易碎的，碎性的
17. unevenly ['ʌni:vənli] *adv.* 不平地
18. comparative [kəm'pærətiv] *a.* 相当的，比较的
19. panel ['pænl] *n.* 面板
20. dosage ['dəusidʒ] *n.* 剂量，用量
21. humidity [hju:'miditi] *n.* 湿度
22. hardened ['hɑ:dənd] *a.* 坚硬的，坚毅的

阅读材料

钢纤维加筋微量硅粉喷混凝土

近年来，在喷混凝土技术的发展中，两个最重要的技术发展是硅粉作为添加剂和钢纤维加固技术的引入。

硅粉或微粒硅是硅铁金属工业的副产品，也是一种非常细的火山灰。火山灰是一种黏结材料，它与水泥水化过程中产生的钙氢氧化物发生反应。加水泥重量的 8%~13%硅粉，可以使喷混凝土的抗压强度达到一般喷混凝土混合物强度的 2 或 3 倍。其结果是非常坚硬、不透水且具有耐久性。其他优点包括减少反弹、改善挠曲强度、增强与岩体的胶结，由于它的黏着性强，单次喷施厚度可达到 200 mm。然而，当使用湿混法时，黏性减小了材料的和易性，要恢复和易性需添加超级塑性剂。

自从 20 世纪 70 年代引入钢纤维增强喷混凝土以来，作为传统的钢丝网加固普通喷混凝土的替代技术，已经在世界范围内得到接受。在喷混凝土中，加筋的作用是增加了脆性材料的延性。正如先前所述，只有在地下洞室围岩出现变形的情况下，才进行岩石支护承担更大的荷载。这意味着，除非系统具有足够的延性以适应这种变形，否则大的非均匀分布的非弹性变形可能会导致超载并导致支护系统的破坏。

典型的钢纤维硅粉喷混凝土混合物的设计概括于表 16.1。在采用喷混凝土方案时，这些配合材料仅作为工作的起点，有时，寻求专家的帮助对混合材料进行调整以适应现场的特殊要求可能是必要的。在许多干混法的应用中，购买袋装 1 500 kg 的已经混合的喷混凝土材料非常便利，如图 16.3 所示。

图 16.4 给出了最近在北美市场上可以买到的钢纤维的类型。它们除了在喷混凝土上的应用之外，这些钢纤维同样广泛地应用于建筑物的混凝土地板、机场跑道以及其他类

似的方面。

Wood 等(1993)经过一系列试验，介绍了对图 16.4 所示钢纤维在加筋喷混凝土中应用的综合对比研究结果。普通和钢纤维硅粉喷混凝土的试样是经在垂直平面上用湿、干混法喷射而制备的。钢纤维试样都包含同一种类的 60 kg/m^3 的钢纤维掺量(见表 16.1)。所有的试样均是在控制相对湿度的条件下进行养护，并且均在喷射后 7 天进行试验。

这些试验结果表明，在硅粉混凝土中加入钢纤维，使硬化后的喷混凝土抗压强度和挠曲强度增加了 20%。在所有的对钢纤维试样的试验中，与普通试样相比，延性均有明显的增加。不同类型的钢纤维给出的改善程度不同，但发现所有试验结果均超出了北美通常所规定的性能水平。

Unit 17

Text

Rockbolts

Rockbolts and dowels have been used for many years for the support of underground excavations and a wide variety of bolt and dowel types have been developed to meet different needs which arise in mining and civil engineering.

Rockbolts generally consist of plain steel rods with a mechanical anchor at one end and a face plate and nut at the other. They are always tensioned after installation. For short term applications the bolts are generally left ungrouted. For more permanent applications or in rock in which corrosive groundwater is present, the space between the bolt and the rock can be filled with cement or resin grout.

Dowels or anchor bars generally consist of deformed steel bars which are grouted into the rock. Tensioning is not possible and the load in the dowels is generated by movements in the rock mass. In order to be effective, dowels have to be installed before significant movement in the rock mass has taken place. Figure 17.1 illustrates a number of typical rockbolt and dowel applications that can be used to control different types of failure that occur in rock masses around underground openings.

The move towards larger underground excavations in both mining and civil engineering has resulted in the gradual development of cable reinforcement technology to take on the support duties which exceed the capacity of traditional rockbolts and dowels.

Expansion shell rockbolt anchors come in a wide variety of styles but the basic principle of operation is the same in all of these anchors. As shown in Figure 17.2, the components of a typical expansion shell anchor are a tapered cone with an internal thread and a pair of wedges held in place by a bail. The cone is screwed onto the threaded end of the bolt and the entire assembly is inserted into the hole that has been drilled to receive the rockbolt. The length of the hole should be at least 100 mm longer than the bolt otherwise the bail will be dislodged by being forced against the end of the hole. Once the assembly is in place, a sharp pull on the end of the bolt will seat the anchor. Tightening the bolt will force the cone further into the wedge thereby increasing the anchor force.

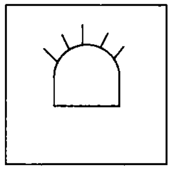
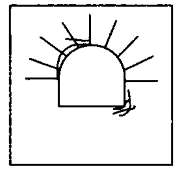
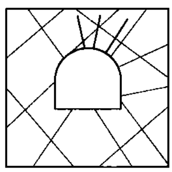
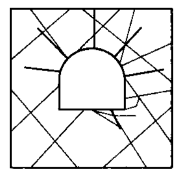
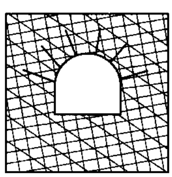
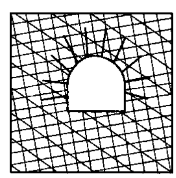
	Low stress levels	High stress levels
Massive rock	 Massive rock subjected to low in situ stress levels. No permanent support. Light support may be required for construction safety	 Massive rock subjected to high in situ stress levels. Pattern rockbolts or dowels with mesh or shotcrete to inhibit fracturing and to keep broken rock in place
Jointed rock	 Massive rock with relatively few discontinuities subjected to low in situ stress conditions. Spot bolts located to prevent failure of individual blocks and wedges. Bolts must be tensioned	 Massive rock with relatively few discontinuities subjected to high in situ stress conditions. Heavy bolts or dowels. Inclined to cross rock structure. With mesh or steel fibre reinforced shotcrete on roof and sidewalls
Heavily jointed rock	 Heavily jointed rock subjected to low in situ stress conditions. Light pattern bolts with mesh and/or shotcrete will control raveling of near surface rock pieces.	 Heavily jointed rock subjected to high in situ stress conditions. Heavy rockbolt or dowel pattern with steel fibre reinforced shotcrete. In extreme cases, steel sets with silding joints may be required. Invert struts or concrete floor slabs may be required to control floor heave

Figure 17.1 Typical rockbolt and dowel applications to control different types of rock mass failure during tunnel driving

These expansion shell anchors work well in hard rock but they are not very effective in closely jointed rocks and in soft rocks, because of deformation and failure of the rock in contact with the wedge grips.

At the other end of the rockbolt from the anchor, a fixed head or threaded end and nut system can be used. In either case, some form of faceplate is required to distribute the load from the bolt onto the rock face. In addition, a tapered washer or conical seat is needed to compensate for the fact that the rock face is very seldom at right angles to the bolt. A wide variety of faceplates and tapered or domed washers are available from

rockbolt suppliers.

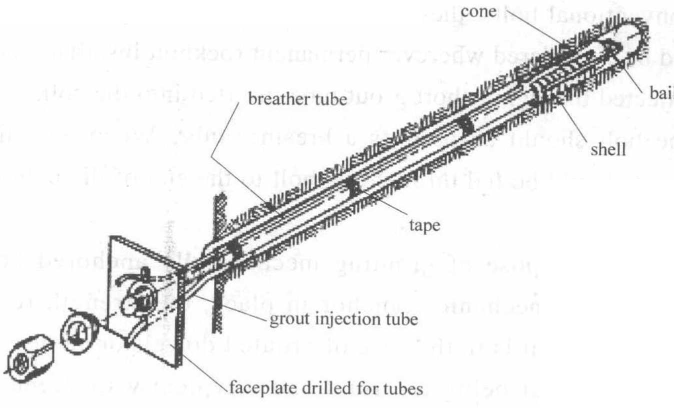


Figure 17.2 Components of a mechanically anchored rockbolt with provision for grouting

In general, threads on rockbolts should be as coarse as possible and should be rolled rather than cut. A fine thread is easily damaged and will cause installation problems in a typical underground environment. A cut thread weakens the bolt and it is not unusual to see bolts with cut threads that have failed at the first thread at the back of the nut. Unfortunately, rolled thread bolts are more expensive to manufacture and the added cost tends to limit their application to situations where high strength bolts are required.

Tensioning of rockbolts is important to ensure that all of the components are in contact and that a positive force is applied to the rock. In the case of light "safety" bolts, the amount of tension applied is not critical and tightening the nut with a conventional wrench or with a pneumatic torque wrench is adequate. Where the bolts are required to carry a significant load, it is generally recommended that a tension of approximately 70% of the capacity of the bolt be installed initially. This provides a known load with a reserve in case of additional load being induced by displacements in the rock mass.

One of the primary causes of rockbolt failure is rusting or corrosion and this can be counteracted by filling the gap between the bolt and the drillhole wall with grout. While this is not required in temporary support applications, grouting should be considered where the ground-water is likely to induce corrosion or where the bolts are required to perform a "permanent" support function.

The traditional method of grouting uphole rockbolts is to use a short grout tube to feed the grout into the hole and a smaller diameter breather tube, extending to the end of the hole, to bleed the air from the hole. The breather tube is generally taped to the bolt shank and this tends to cause problems because this tube and its attachments can be damaged during transportation or insertion into the hole. In addition, the faceplate has to be drilled to accommodate the two tubes, as illustrated in Figure 17.2. Sealing the system for grout injection can be a problem.

Many of these difficulties are overcome by using a hollow core bolt. While more expensive than conventional bolts, these hollow bolts make the grouting process much more reliable and should be considered wherever permanent rockbolt installations are required. The grout should be injected through a short grout tube inserted into the collar of the hole and the central hole in the bolt should be used as a breather tube. When installing these bolts in downholes, the grout should be fed through the bolt to the end of the hole and the short tube used as a breather tube.

Since the primary purpose of grouting mechanically anchored bolts is to prevent corrosion and to lock the mechanical anchor in place, the strength requirement for the grout is not as important as it is in the case of grouted dowels or cables. The grout should be readily pumpable without being too fluid and a typical water/cement ratio of 0.4 to 0.5 is a good starting point for a grout mix for this application. It is most important to ensure that the annular space between the bolt and the drillhole wall is completely filled with grout. Pumping should be continued until there is a clear indication that the air has stopped bleeding through the breather tube or that grout is seen to return through this tube.

New Words and Expressions

1. rockbolt['rɔk,bəult] *n.* 岩石锚杆
2. cable ['keibl] *n.* 锚索
3. rod [rɔd] *n.* 条，杆
4. nut [nʌt] *n.* 螺帽，螺母
5. resin ['rezin] *n.* 树脂
6. bar [bɑː(r)] *n.* 条钢，铁条
7. duty ['djuːti] *n.* 荷载
8. issue ['isjuː] *n.* 问题
9. tapered['teipəd] *a.* 锥形的
10. thread [θred] *n.* 螺纹，螺丝
11. wedge [wedʒ] *n.* 楔形体，楔形物
12. in place (安装)就位，安装好，在原位
13. bail [beil] *n.* 钩，卡箍
14. cone [kəun] *n.* 锥
15. screw [skruː] *v.* 拧紧
16. assembly [ə'sembli] *n.* 组合，装配
17. insert [in'səːt] *vt.* 插入，嵌入，引入
18. dislodge [dis'lɔdʒ] *vt.* 移动，挪动
19. cartridge ['kɑːtridʒ] *n.* 夹头
20. right [rait] *a.* 直角的，正交的
21. dome [dəum] *n.* 圆顶
22. roll [rəul] *v.* 轧制
23. cut [kʌt] *v.* 切割
24. wrench [rentʃ] *n.* 扳手
25. pneumatic [nju(ː)'mætik] *a.* 气动的
26. torque [tɔːk] *n.* 转矩，扭矩
27. rust [rʌst] *n.* 氧化，上锈
28. corrosion [kə'rəuʒən] *n.* 腐蚀，侵蚀
29. shank [ʃæŋk] *n.* 螺钉的无纹部分
30. seal [siːl] *v.* 密封
31. pumpable ['pʌmpəbl] *a.* 可用泵抽的
32. annular ['ænjulə] *a.* 环的，环状的
33. dowel ['dauəl] *n.* 销钉，锚栓

岩石锚杆

多年来，岩石锚杆和锚栓已经应用于地下工程开挖支护中，人们开发了各种各样的

岩石锚杆和锚栓以满足在采矿和土木工程等不同方面的需求。

岩石锚杆通常由一端具有机械锚头、另一端具有垫板和螺帽的普通钢筋构成。它们在安装后通常进行张拉。对短期使用来说锚杆一般不进行注浆。对于长期使用或岩石中的地下水具有腐蚀性时，锚杆与岩体之间的间隙用水泥或树脂浆填注。

锚栓或锚固钢筋一般由插入岩石的成型钢筋组成并注浆。不可能发生张拉，锚栓的荷载由岩体的变位而引起。为了使这些锚栓起作用，必须在岩体发生明显位移前安装。图 17.1 说明了在工程上采用的岩石锚杆和锚栓，可用于控制地下洞室围岩所发生的不同形式的破坏。

在采矿工程和土木工程中，地下工程规模越来越大的趋势带动了锚索加固技术的不断发展，它所起的作用，超过了传统的岩石锚杆和锚栓。

胀壳式岩石锚杆具有各种各样的类型，但是在所有这些锚杆中，工作基本原理是相同的。如图 17.2 所示，典型的胀壳式锚杆有带内丝的锥形螺母和由顶板固定的一对锲体。锥形螺母在锚杆的具有螺丝的一端被拧紧，整个装配过程是将锚杆插入已钻成的锚杆孔内。孔的长度至少要比锚杆的长度长 100 mm，否则，顶板将由于钻孔末端的作用力使卡箍卸载。一旦装配到位，将锚杆末端猛地一拉，使锚杆到位。上紧锚杆迫使锥体进入楔体，从而增加锚固力。

胀壳式锚固器在坚硬岩石中工作良好，但在与楔体啮合的节理带和软岩中由于岩石变形和破坏，这种方法不是非常有效。

锚固器锚杆的另一端，可采用固定头或螺纹端和螺帽系统。在任一情况下，均需要某种类型的垫板将锚杆的荷载传到岩石表面上。另外，因为岩石表面很少与锚杆呈正交，需要一个锥型垫或锥型座进行调整。岩石锚杆生产商供应各种各样垫板和锥型或圆型垫圈。

一般来说，岩石锚杆的螺纹应尽可能粗，并且应该是轧制螺纹而不是切割螺纹。细螺纹容易损坏，并且在典型的地下环境中易产生安装问题。切割螺纹使锚杆弱化，经常看到切割螺纹的锚杆在螺帽后面的第一丝扣处发生损坏。遗憾的是，轧制螺纹锚杆制造价格昂贵，增加的费用限制了它只能在需要高强度锚杆的地方使用。

岩石锚杆的张拉是重要的，它要保证所有的部分相互接触，并且在岩石上施加压力。在使用对安全性要求较小的锚杆时，所施加的张力的大小并不重要，使用常规的扳手或气压扭矩式扳手拧紧螺帽就已足够。在需要锚杆承担大荷载的地方，一般建议在安装的初期，施加锚杆的张力为允许荷载的 70%。在岩体中因位移产生附加荷载时，这种做法提供了一个保守的已知的荷载。

岩石锚杆破坏的主要原因之一是锈蚀或腐蚀，这些可采用在锚杆和钻孔壁之间充填浆液的办法进行防治。这些措施在临时支护时并不需要，但在地下水有可能产生腐蚀作用或锚杆需要作为永久支护的地方，应尽可能考虑使用注浆锚杆。

在方向向上的岩石锚杆孔中进行注浆的传统方法是使用短注浆管把浆液灌入孔中，将一个直径较小的排气管插到钻孔的底部，从钻孔中排气。排气管通常和锚杆捆在一起，这种方法有时会产生问题，因为这些排气管和它的捆扎物在运输或插进钻孔的过程中可

能会遭受破坏。此外，还要在面板上钻孔，以容纳排气管和注浆管的需要，如图 17.2 所示。注浆系统的封闭也可能存在问题。

很多此类困难均可用空心锚杆克服。这种锚杆比常规锚杆要贵，但它使注浆过程更可靠，可以在需要安装永久锚杆的地方考虑使用这种锚杆。浆液通过一个短的注浆管注浆直到孔的周边，锚杆的中心孔用做排气管。当在向下的孔中安装这类锚杆时，灌浆应通过锚杆灌到钻孔底端，短管用做排气管。

从机制上讲，注浆的目的是要防腐蚀并把机械锚头固定到相应的部位，浆液的强度要求不像对注浆锚栓或锚索要求的那样重要。浆液应该能用泵抽送并且不太稀，一般情况下，采用水灰比为 0.4~0.5 的浆液混合物十分可行。保证锚杆和钻孔壁之间的环形孔隙完全充填浆液是很重要的。泵送应该连续进行，直到有清楚的证据表明，排气管不再排气或浆液已经开始从排气管排出为止。

Reading Material

Cables

A comprehensive review of cable support in underground mining has been given in a book by Hutchinson and Diederichs (1996). This book is highly recommended for anyone who is concerned with the selection and installation of cable support for either mining or civil engineering applications.

Some of the main cable types used by mining have been summarised by Windsor (1992) and are illustrated in Figure 17.3.

1 Bond strength

The forces and displacements associated with a stressed cable grouted into a borehole in rock are illustrated in Figure 17.4.

As the cable pulls out of the grout, the resultant interference of the spiral steel wires with their associated grout imprints or flutes causes radial displacement or dilation of the interface between the grout and the cable. The radial dilation induces a confining pressure that is proportional to the combined stiffness of the grout and the rock surrounding the borehole. The shear stress, which resists sliding of the cable, is a product of the confining pressure and the coefficient of friction between the steel wires and the grout. Shear strength, therefore, increases with higher grout strength, increases in the grout and the rock stiffness and increases in the confining stresses in the rock after installation of the cable. Conversely, decrease in shear strength can be expected if any of these factors decrease or if the grout crushes.

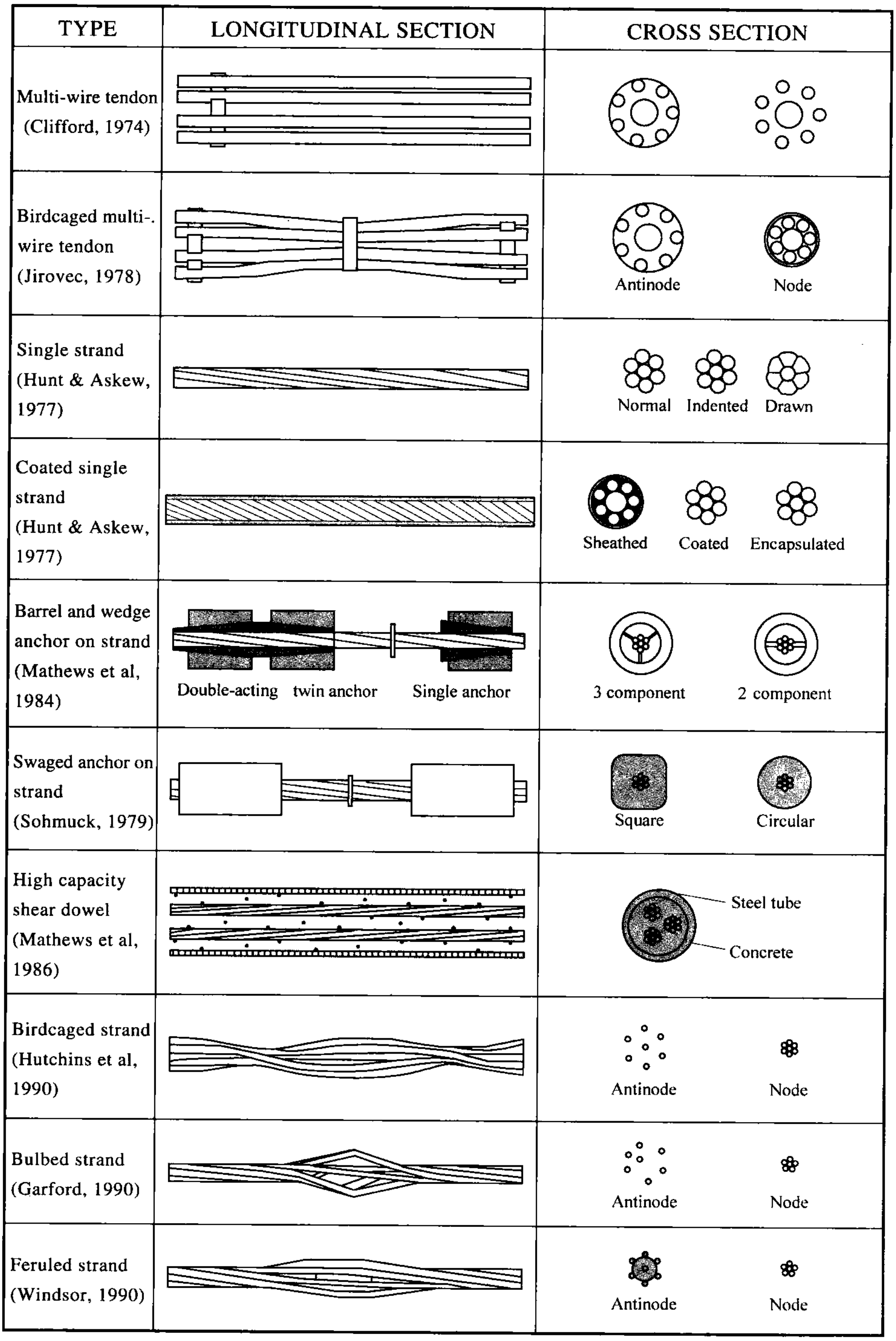


Figure 17.3 Summary of the development of cable reinforcing systems for underground mining (Windsor, 1992)

2 Groots and grouting

The question of grout quality has always been a matter of concern in reinforcement systems for underground construction. One of the critical factors in this matter has been the evolution of grout pumps capable of pumping grouts with a low enough water/cement ratio (by weight) to achieve adequate strengths. Fortunately, this problem has now been overcome and there is a range of grout pumps on the market which will pump very viscous grouts and will operate reliably under typical underground conditions.

The results of a comprehensive testing programme on Portland cement grouts have been summarised by Hyett et al (1992) and Figures 17.5 and Figures 17.6 are based upon this summary. Figure17.5 shows the decrease in both 28 day uniaxial compressive strength and deformation modulus with increasing water/cement ratio. Figure 17.6 gives Mohr failure envelopes for three water/cement ratios.

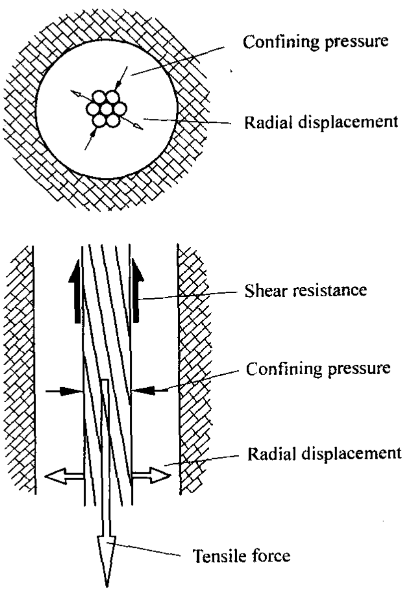


Figure 17.4 Forces and displacements associated with a stressed cable grouted into a borehole in rock

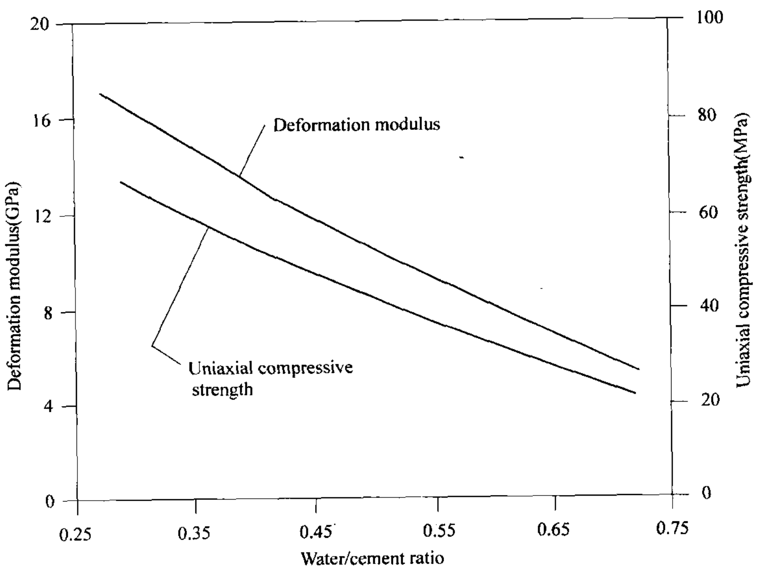
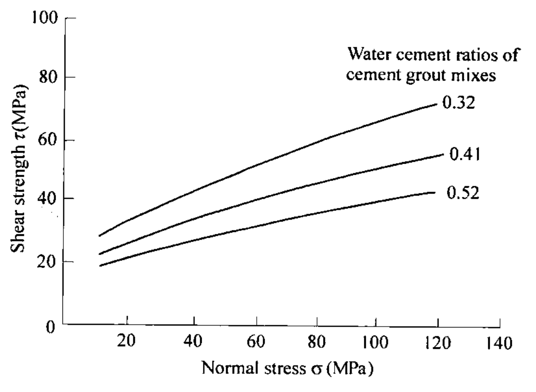


Figure 17.5 Relationship between the water/cement ratio and the average uniaxial compressive strength an deformation modulus for grouts testes at 28 days



w/c ratio	σ_c (Mpa)	constant (m)	constant (s)	Friction angle φ (°)	Cohesion c (Mpa)
0.32	78	3.05	1	24	25
0.41	54	2.14	1	20	19
0.52	38	1.67	1	17	14

Figure 17.6 Mohr failure envelopes for the peak strength of grouts with different water/cement ratios, tested at 28 days

These results show that the properties of grouts with water/cement ratios of 0.35 to 0.4 are significantly better than those with ratios in excess of 0.5. However, Hyett et al found that the scatter in test results increased markedly for water/cement ratios less than 0.35. The implication is that the ideal water/cement ratio for use with cable reinforcement lies in the range of 0.35 to 0.4(Table 17.1).

Table 17.1 The characteristics of grouts with different water/cement ratios

w/c ratio	Characteristics at end of grout hose	Characteristics when handled
< 0.30	Dry, stiff sausage structure	Sausage fractures when bent. Grout too dry to stick to hand. Can be rolled into balls
0.30	Moist sausage structure. "Melts" slightly with time	Sausage is fully flexible. Grout will stick to hand. Easily rolled into wet, soft balls
0.35	Wet sausage structure. Structure "melts" away with time	Grout sticks readily to hand. Hangs from hand when upturned
0.4	Sausage structure lost immediately. Flows viscously under its own weight to form pancake	Grout readily sticks to hand but can be shaken free
0.5	Grout flows readily and splashes on impact with ground	Grout will drip from hand - no shaking required

New Words and Expressions

1.compressive [kəm'presiv] *a.* 综合性的

2.review [ri'vju:] *n.* 评论，回顾

3.bond [bɔnd] *n.* 黏结，胶结

4.spiral ['spaiərəl] *a.* 螺旋的

5.imprint [im'print] *n.* 盖印
6.flute [flu:t] *n.* 凹槽，螺丝槽
7.dilation [dai'leiʃən] *n.* 膨胀，扩大(展)
8.coefficient [kəui'fiʃənt] *n.* 系数
9.grout [graut] *n.* (灰，砂，水泥)浆
10.viscous['viskəs] *a.* 黏性的，黏稠的
11.uniaxial compressive strength 单轴压缩强度
12.deformation modulus 变形模量
13.water/cement ratio 水灰比
14.Mohr failure envelope 莫尔破坏包络线
15.scatter ['skætə] *v.* 分散
16.sausage ['sɔsidʒ] *n.* 香肠
17.hose[həuz] *n.* 软管，胶皮管

阅读材料

锚 索

Hutchinson 和 Diederichs (1996)在其著作中全面总结了锚索支护在地下采矿业中的应用。这本书极力推荐给在采矿业和土木工程行业中从事选取和安装锚索支护的专业人员。

Windsor (1992)总结了在采矿业中使用锚索的主要类型，如图 17.3 所示。

一、黏结强度

在岩石钻孔中与注浆应力锚索相关的力和位移见图 17.4。

当锚索从浆体中拔出时，螺旋状钢绞线与相关的灌浆印痕或凹槽所引起的相互作用会引起锚索和注浆界面之间径向膨胀和位移。径向膨胀会减少围压，此围压与浆体和钻孔周围岩石综合刚度成正比。阻止锚索滑动的剪应力由围压和钢绞线与浆体之间的摩擦力产生。因此，在锚索安装以后，抗剪强度随浆体强度的增加而增加，随浆体和岩石刚度的增加而增加，同时也随锚索安装后岩石围压的增加而增加。反过来讲，如果这些值减小或浆体破裂，抗剪强度可能会减小。

二、浆体和注浆

在地下工程中，浆体的质量总是涉及到加固问题。其中的一个主要因素是灌浆泵的发展，灌浆泵应该能泵取相当低水灰比(按重量)的浆液同时也能达到足够的强度。值得庆幸的是，这些难题已经克服，市场上有各种各样的灌浆泵可泵取很黏的浆液，在特殊的地下条件下，可以可靠地工作。

Hyett(1992)等对波特兰(Portland)水泥浆液的综合试验结果进行了总结，图 17.5 和图 17.6 是试验结果的图示。图 17.5 表明，28 天龄期的单轴抗压强度和变形模量随水灰比的增加而减小。图 17.6 给出了 3 种水灰比的莫尔破坏包络线。

这些结果表明水灰比为 0.35~0.4 的浆液性质要比水灰比超过 0.5 的浆液好很多。然而，Hyett 等发现水灰比小于 0.35 的浆液，试验结果的离散性显著增加。这意味着用于锚索加固的理想水灰比应位于 0.35~0.4 之间(见表 17.1)。

Unit 18

Text

Stability Analysis of Tunnel Excavation

A spillway tunnel for an embankment dam is to be constructed in a poor quality sandstone. The excavated diameter of the tunnel is about 13 m and the cover over the roof is 8 m. The tunnel is to have a 1.3 m thick un-reinforced concrete lining and, after placement of this lining, a 28 m high portion of the rockfill dam will be constructed over the tunnel.

The questions to be addressed are:

(1)What support is required in order to excavate the tunnel safely under the very shallow cover?

(2)Is the proposed top heading and bench excavation sequence, using drill and blast methods, appropriate for this tunnel?

(3)How will the concrete lining respond to the loading imposed by the placement of 28 m of rockfill over the tunnel?

In order to answer these questions a series of two-dimensional finite element analyses were carried using the program PHASE^2. The first of these analyses examined the stability and support requirements for the top heading excavation. The final analysis included the entire excavation and support sequence and the placement of the rockfill over the tunnel.

The rock mass is a poor quality sandstone that, being close to surface, is heavily jointed. The mechanical properties assumed for this rock mass are a cohesive strength c = 0.04 MPa, a friction angle ϕ =40°and a modulus of deformation E =1 334 MPa. No in situ stress measurements are available but, because of the location of the tunnel in the valley side, it has been assumed that the horizontal stress normal to the tunnel axis has been reduced by stress relief. The model is loaded by gravity and a ratio of horizontal to vertical stress or 0.5 is assumed.

A simplified version of the model was used to analyse the stability and support requirements for the top heading. This model did exclude the concrete lining and the bench excavations.

The first model was used to examine the conditions for a full-face excavation of the top heading without any support. This is always a useful starting point in any tunnel support design study since it gives the designer a clear picture of the magnitude of the problems that have to be dealt with.

The model was loaded in two stages. The first stage involved the model without any

excavations and this was created by assigning the material within the excavation boundary the properties of the surrounding rock mass. This first stage is carried out in order to allow the model to consolidate under gravitational loading. It is required in order to create a reference against which subsequent displacements in the model can be measured.

The results of the analysis are illustrated in Figure 18.1, that shown the extent of yield in the rock mass surrounding the top heading, and Figure 18.2 that shows the induced displacements around the tunnel.

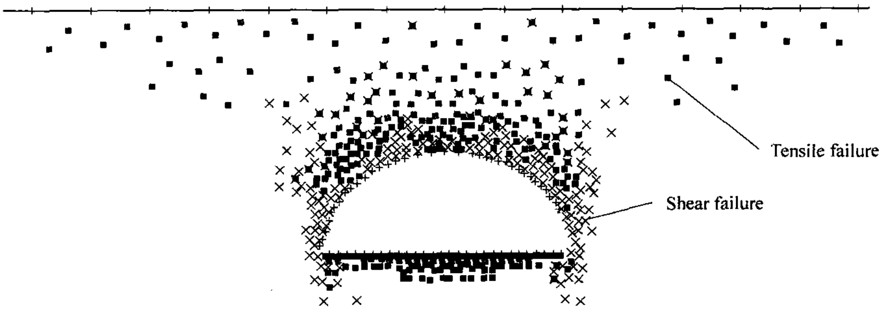


Figure 18.1 Yield in the rock mass surrounding the top heading excavation with no support installed

The large amount of yield in the rock mass overlying the top heading suggests that this excavation will be unstable without support. This view is supported by the displacements shown in Figure 18.2.

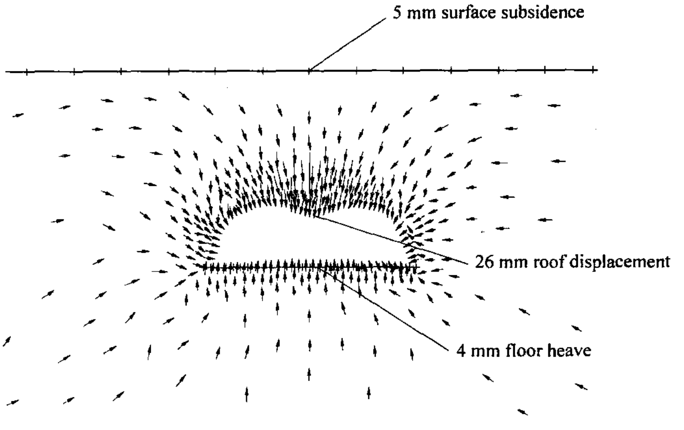


Figure 18.2 Displacements induced in the rock mass by the excavation of an unsupported top heading

The reader may be surprised that the displacement in the roof of the tunnel is only 26 mm when the extent of the yield zone suggests complete collapse of the roof. It has to be remembered that PHASE^2 is a small strain finite element model and that it cannot accommodate the very large strains associated with the complete collapse of a tunnel. In examining Figure 18.2 it is more important to look at the shape of the overall displacement

profile than the magnitude of the displacements. A rock mass will not tolerate the differential displacements illustrated and progressive ravelling leading to ultimate collapse would almost certainly result from the excavation of an unsupported top heading.

A general rule of thumb used by experienced tunnellers is that an underground excavation will not be self-supporting unless the cover over the tunnel exceeds 1.5 times the span of the opening. This is a typical situation that occurs when excavating tunnel portals are there are several options available for dealing with the problem. One of these options is to use a shotcrete lining to stabilize the rock mass above the tunnel. A finite element analysis of this option shows that a 50 mm thick layer of fully hardened shotcrete (uniaxial compressive strength of 30 MPa) is sufficient to stabilize the tunnel. The problem is how to get a fully hardened layer of shotcrete into an advancing tunnel heading. A second problem is whether the workers would have sufficient confidence in such a solution to work in the tunnel.

One project on which this solution was used was the construction of an 8 m span diversion tunnel for a dam. The rock mass was a very weakly cemented limestone that could be excavated by hand but which had sufficient strength that it was marginally self-supporting. The Scandinavian contractor on the project had used shotcrete for many years and the very experienced tunnellers had complete confidence in working under a cover of shotcrete. The tunnel was not on the critical path of the project and so construction could proceed at a sufficiently slow pace to allow the shotcrete to set before the next advance. A layer of un-reinforced shotcrete was the sole support used in this tunnel, with occasional steel sets embedded in the shotcrete where ground conditions were particularly difficult.

In the case of the top heading in sandstone under consideration here, the shotcrete solution was rejected because, in spite of the finite element analysis, the designers did not have sufficient confidence in the ability of the shotcrete layer to support the large span of blocky sandstone. In addition, the contractor on this dam project did not have a great deal of experience in using shotcrete in tunnels and it was unlikely that the workers would have been prepared to operate under a cover of shotcrete only.

Another alternative that is commonly used in excavating tunnel portals is to use steel sets to stabilise the initial portion of the tunnel under low cover. This solution works well in the case of small tunnels but, in this case, a 13 m span tunnel would require very heavy sets. An additional disadvantage in this case is that the installation of sets would permit too much deformation in the rock mass. This is because the steel sets are a passive support system and they only carry a load when the rock mass has deformed onto the sets. Since this tunnel is in the foundation of a dam, excessive deformation is clearly not acceptable because of the additional leakage paths which would be created through the rock mass.

The solution finally adopted was "borrowed" from the mining industry where untensioned fully grouted dowels are frequently used to pre-support the rock mass above underground excavations. In this case, a pattern 3 m×3 m pattern of 15 m long 60 ton capacity

cables were installed from the ground surface before excavation of the top heading was commenced. When these cables were exposed in the excavation, face plates were attached and the excess cable length was cut off. In addition, a 2 m × 2 m pattern of 6 m long mechanically anchored rockbolts were installed radially from the roof of the top heading.

The results of an analysis of this support system are illustrated in Figure 18.3 and Figure 18.4 which show the extent of the yield zone and the deformations in the rock mass above the top heading.

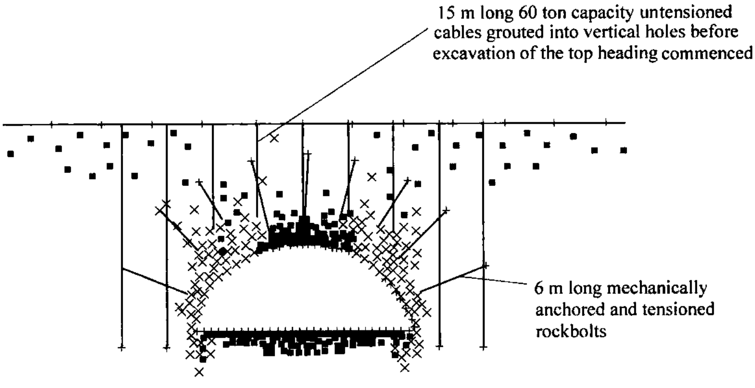


Figure 18.3 Yield zone in the rock mass surrounding the top heading supportes by means of pre-placed grouted cabled and mechanically anchored and tensioned rockbolts

Comparing Figure 18.1 and Figure 18.3 shows that the extent of the yield zone is only reduced by a small amount by the enstallation of the support system. This is not surprising since some deformation of the rock mass is required in order to mobilize the supporting loads in the untensioned cables. This deformation occurs as a result of failure of the rock mass.

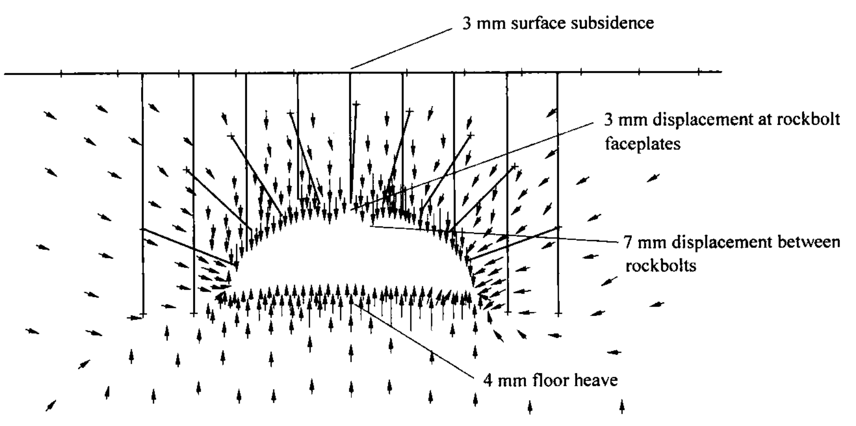


Figure 18.4 Displacements in the rock mass supported by means of preplaced grouted cables and tensioned rockbolts

Figure 18.4 shows that the displacements in the roof of the top heading have been reduced substantially as a result of the placement of the support. However, a small problem remains and that is the excessive displacement of the rock between the rockbolt faceplates

which are spaced on a 2 m × 2 m grid. Unless this displacement is controlled it can lead to progressive ravelling of the rock mass.

Only a small surface pressure is required to control this ravelling and this could be achieved by means of a layer of mesh or shotcrete of by the installation of light steel sets. In this case the latter solution was adopted because of the sense of security which these gave for the workers in the tunnel.

New Words and Expressions

1.version ['və:ʃən] *n.* 方案，型(式)，版本
2.model ['mɔdl] *n.* 模型
3.heading ['hediŋ] *n.* 导洞，导坑
4.lining ['lainiŋ] *n.* 衬砌
5.bench [bentʃ] *n.* 台阶
6.consolidate [kən'sɔlideit] *v.* 加固
7.ravel ['rævəl] *v.* 剥落
8.a general rule of thumb 经验法则
9.portal ['pɔ:təl] *n.* 入口
10.shotcrete['ʃɔtkri:t] *n.* 喷射混凝土
11.diversion [dai'və:ʃən] *n.* 导流
  diversion tunnel 导流洞
12.marginally ['mɑ:dʒinəli] *adv.* 在一定程度上，在边上
13.contractor[kən'træktə] *n.* 承包商
14.embed [im'bed] *v.* 埋置，嵌入
15.sandstone ['sændstəun] *n.* 砂岩
16.passive support system 被动支护系统
17.leakage ['li:kidʒ] *n.* 渗漏
18.mining ['mainiŋ] *n.* 开矿，采矿，开采
19.grout [graut] *n.* 灌浆
20.dowel ['dauəl] *n.* 销钉，钢筋
21.pattern ['pætən] *n.* 模式，形式
22.commence [kə'mens] *v.* 开始
23.mechanically [mi'kænikəli] *adv.* 机械地
24.radial ['reidjəl] *a.* 径向的，放射状的
25.mobilise ['məubilaiz] *vt.* 动员，调动

洞室开挖稳定分析

某土石坝工程在质量差的砂岩区开挖溢洪隧洞。其开挖直径 13 m，顶部埋深 8 m。隧洞有 1.3 m 厚的普通混凝土衬砌，衬砌浇筑后在隧洞上修建 28 m 高的土石坝出水口。

面临的问题是：

(1)在浅部开挖时，为保证溢洪隧洞的安全所需的支护形式？

(2)在隧洞开挖时比较适用的是钻爆法施工，开挖过程中如何确定顶部上导洞和分步开挖的顺序？

(3)混凝土衬砌与隧洞上 28 m 高的堆石荷载之间的作用是怎样的？

为解决上述问题，采用 PHASE^2 程序进行了一系列的平面有限元分析。首先对上导洞开挖的稳定性及所需要的支护形式进行分析，然后对全断面开挖、支护顺序和堆石对隧洞衬砌的影响进行分析。

岩体为质量差的砂岩，近地表浅部节理发育。其力学特性建议为：黏聚力 c =0.04 MPa，内摩擦角 ϕ=40°，变形模量 E =1 334 MPa。没有现场地应力量测资料，由于隧洞位于谷坡，可以假定垂直隧洞轴线的水平应力由于应力释放而减小，并且认为水平与垂直应力之比为 0.5，计算模型考虑自重荷载。

一简化的计算模型可用于洞室顶拱稳定性分析和支护要求。该模型不包括混凝土衬砌和台阶开挖。

初始模型用来检查在没有任何支护情况下的上导洞全断面开挖的情况。该模型常用于隧洞支护设计研究开始阶段，因为模型可以为设计者提供较清楚的将要处理问题的难度。

模型的加载分两个阶段。首先是没有开挖情况下的模型，此模型是在开挖边界内利用给定岩石材料特性建立起来。第一阶段实施是为了在重力荷载条件下对模型加固。相对于模型其后的位移可以量测到，则创建一个参考系是必要的。

分析结果如图 18.1 所示，图中显示了上导洞围岩的屈服范围；而图 18.2 则显示了隧洞次生位移的情况。

上导洞洞顶岩体的大范围屈服说明在没有支护条件下的开挖是不稳定的。图 18.2 的位移也说明了这一点。

大家感到奇怪的是当屈服带的范围被暗示洞顶会全部坍塌时，隧洞顶部仅有 26 mm 的位移。但应记住，$PHASE^2$ 是一个关于小应变模型的有限元程序，并不适用于隧洞整体塌落的大应变工况。从图 18.2 可看出，考虑整体位移形状远比位移量重要，而且岩体将不能承受图中所示的差异性位移，上导洞不做支护开挖，由于渐进式剥落，最终导致洞室完全塌落是肯定的。

经验丰富的隧洞建设者采用的经验法则是隧洞上部覆盖层厚度大于 1.5 倍洞室跨度，地下开挖才可达到自承支护。对所涉及的问题来说，当开挖洞口有几种选取方案时，上面情况才会发生。这些方案之一是采用喷混凝土衬砌来维持隧洞顶部岩体的稳定。这一方案有限元分析表明，50 mm 厚的充分硬化喷混凝土层(单轴压缩强度 30 MPa)对于隧洞的稳定已经足够。问题是如何把充分硬化的喷射混凝土注入到前方的洞室端部。其次是施工者是否有信心来解决隧洞的这一问题。

某工程在为大坝建一条 8 m 跨度的导流洞时采用了喷混凝土衬砌。围岩为弱胶结的灰岩，可用手工掘进，但有足够的强度在一定程度上达到自承作用。斯堪的纳维亚(Scandinavian)承包商在工程上采用喷混凝土技术已多年，非常有经验的隧道建设者完全有信心在喷射过混凝土的隧道中施工。该隧洞并不是工程的关键隧洞，建设者有充分的时间进行喷混凝土施工。在隧洞中喷混凝土技术是常用的支护措施，对隧洞地质条件特别差的地段，采用预埋在喷混凝土层中的钢拱架支护。

在砂岩中进行上导行洞开挖，未采用喷混凝土方案，尽管有限元分析结果表明是可以的，但设计者没有充分的信心认为喷混凝土层可以对块状砂岩大跨度洞室进行支护。除此以外，大坝项目的承包商没有隧洞喷混凝土施工的丰富经验，施工人员也不准备在仅有喷混凝土支护条件下施工。

在开挖洞口时另一个通常采用的方法是在洞顶覆盖层较薄的地方用钢架来支护隧洞的进口部分。在小型隧洞中常用此法，但本工程情况 13 m 跨度的隧洞需要高强度的钢架。另一个不利因素是安装钢架时要预留有岩体较大的变形量。这是因为钢架是一个被动的支护系统，只有当岩体变形并与之接触时才可承重。由于隧洞位于坝基中，过大的变形显然不能接受，因为过大的变形会增多渗漏通道。

最终采取的方案借鉴采矿工程的经验，即对地下开挖以上的岩体一般采用非张拉注

浆锚索进行预支护。具体施工时，在上导洞室开挖前，从地表安装间距 3 m×3 m、长 15 m、锚固力 60 t 的锚索。当锚索在开挖面出露时，焊上面板并把多余的锚索切掉。此外，在洞室顶部安装放射状间距 2 m×2 m、长 6 m 的机械锚固的岩石锚杆。

支护系统的分析结果见图 18.3 和图 18.4，图中表明了屈服带的发展程度和上导洞之上岩体的变形情况。

对比图 18.1 和图 18.3 看出，在安装支护系统后，屈服带范围有少量减小。这并不奇怪，因为岩体的某些变形要协调非张拉锚索的支护荷载，而且这些变形是岩体破裂的结果。

图 18.4 表明，上导洞顶拱的位移随着支护的安装显著地减少。然而，仍存在一些小问题，在岩石锚杆面板(以 2 m×2 m 的网格布设)之间的岩石仍存在较大位移。如果不对这些位移进行控制，就可能导致岩体的渐进式剥落破坏。

控制岩体的剥落作用只需要很小的表面压力，可通过挂网或安装轻型钢架喷混凝土来实现。在本例中采用第二种方案，因为隧洞施工者对安全较为敏感。

Reading Material

Analysis of Complete Excavation of Tunnel

Having successfully excavated the top heading of this spillway tunnel, as discussed in the previous section, the next question was how the excavation would behave during benching down and how the concrete lining would tolerate the additional loads imposed by the placement of 28 m of compacted rock fill.

The complete model was used for this investigation and it was found that there were no problems with the excavation of the benches. Figures 18.5 and 18.6 illustrate the yield zone and the displacements of the rock mass surrounding the complete excavation supported by means of cables and rockbolts and, for the purposes of this study, a thin shotcrete lining.

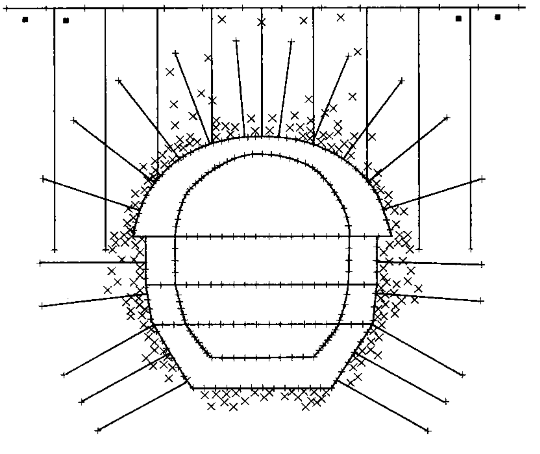


Figure 18.5 Extent of yield in the rock mass surrounding the complete spillway tunnel excavation before placement of the concrete lining

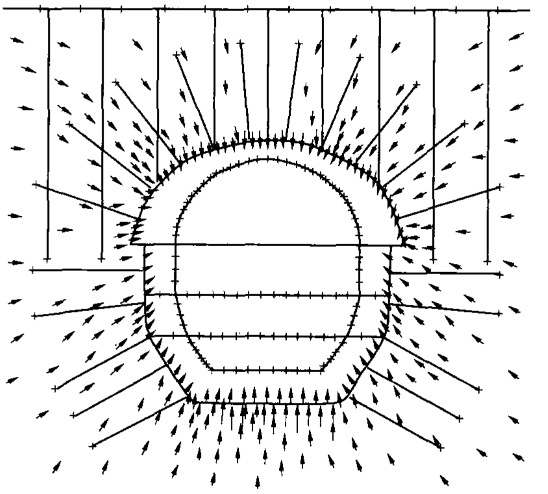


Figure 18.6 Displacements in the rock mass surrounding the complete spillway tunnel excavation. The maximum displacements in the centre of the roof and the centre of the Floor are both 5 mm

The self-weight of the concrete lining indices displacements in the rock mass and these are increased by the imposition of the surface load due to the placement of 28 m of compacted rockfill above the tunnel. The induced displacements are illustrated in Figure 18.7 and Figure 18.8.

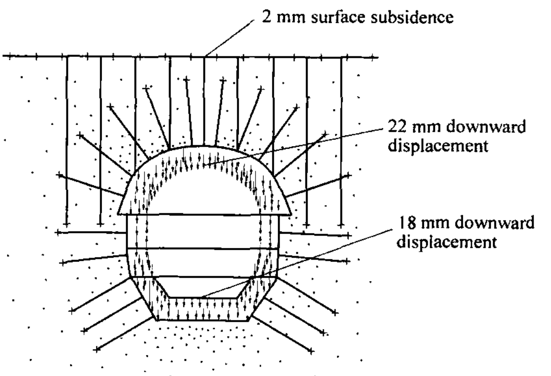


Figure 18.7 Displacements induced as a result of the self-weight of the concrete lining

Figure 18.7 and Figure 18.8 show that significant displacements are induced as a result of the casting of the concrete lining and the subsequent placement of the rockfill above the tunnel. No failure of the concrete lining was shown by this analysis, in spite of the assumption of a very weak concrete (10 MPa uniaxial compressive strength). The only problem that could be anticipated from the placement of the rockfill was the possibility of bending of the entire length of the concrete lining and the formation of tensile cracks normal to the tunnel axis. It was therefore recommended that the concrete lining be carefully inspected for such cracks after the completion of the rockfill. Repair of such cracks by dental concrete and grouting would not be a major problem but, in any case, it proved not to be necessary.

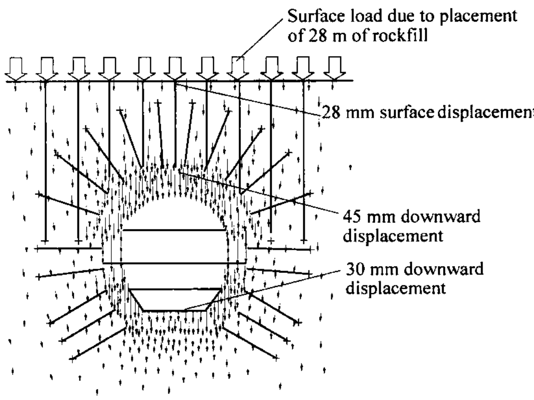


Figure 18.8 Displacements induced as a result of the placement of 28 m of rockfill above the completed tunnel

New Words and Expressions

1.compact ['kɔmpækt] *v.* 压实，压密
2.indices ['indisi:z] index 的复数
3.precede [pri(:)'si:d] *v.* 领先，优先，在……之前
4.demonstrate ['demənstreit] *v.* 论证，证明
5.clarify ['klærifai] *v.* 澄清，阐明
6.credence ['kri:dəns] *n.* 信任，凭证
7.dispel [dis'pel] *v.* 驱散，驱除，消除

阅读材料

洞室全断面开挖分析

如前面章节所述，在泄洪隧洞的上导洞开挖后，接下来的问题是在向下的分步开挖中如何进行施工，如何进行混凝土衬砌来承受 28 m 挤密堆石造成的附加荷载。

用完整模型可进行全开挖研究，而且发现在分步开挖中不存在问题。图 18.5 和图 18.6 显示了利用岩石锚杆和锚索支护全断面隧洞围岩开挖的屈服带和位移，为了达到研究的目的，洞室用薄层喷混凝土衬砌。

混凝土衬砌的自重导致岩体位移，由于在隧洞上方有 28 m 高的压密堆石，地表荷载使岩体位移加剧。图 18.7 和图 18.8 中显示了这些次生的岩体位移。

图 18.7 和图 18.8 表明了由混凝土衬砌和其后隧洞上部放置堆石诱发的位移。在此情况下，尽管采用的是低强度混凝土(单轴抗压强度为 10 MPa)，但混凝土衬砌没有发生破坏。能够从堆石中预测到的问题是混凝土衬砌总长度上弯曲的可能性和垂直于隧洞轴线方向张裂缝的形成。因此，在石料完全填筑后应该对混凝土衬砌的裂缝进行细致的检查。用混凝土补缝和灌浆技术修补裂缝不是主要的问题，并且有时是不必要的。

Unit 19

Text

Numerical Methods of Stress Analysis of Rock Mass

Most underground excavations are irregular in shape and are frequently grouped close to other excavations. These groups of excavations can form a set of complex three dimensional shapes. In addition, because of the presence of geological features such as faults and intrusions, the rock properties are seldom uniform within the rock volume of interest. Consequently, the closed form solutions are of limited value in calculating the stresses, displacements and failure of the rock mass surrounding underground excavations. Fortunately, a number of computer-based numerical methods have been developed over the past few decades and these methods provide the means for obtaining approximate solutions to these problems.

Numerical methods for the analysis of stress driven problems in rock mechanics can be divided into two classes.

Boundary methods, in which only the boundary of the excavation is divided into elements and the interior of the rock mass is represented mathematically as an infinite continuum.

Domain methods, in which the interior of the rock mass is divided into geometrically simple elements each with assumed properties. The collective behaviour and interaction of these simplified elements model the more complex overall behaviour of the rock mass. Finite element and finite difference methods are domain techniques which treat the rock mass as a continuum. The discrete element method is also a domain method which models each individual block of rock as a unique element.

These two classes of analysis can be combined in the form of hybrid models in order to maximize the advantages and minimize the disadvantages of each method. It is possible to make some general observations about the two types of approaches discussed above. In domain methods, a significant amount of effort is required to create the mesh that is used to divide the rock mass into elements. In the case of complex models, such as those containing multiple openings, meshing can become extremely difficult. The availability of highly optimised mesh-generators in many models makes this task much simpler than the case when the mesh had to be created manually. In contrast, boundary methods require only that the excavation boundary be discretized and the surrounding rock mass is treated as an infinite continuum. Since fewer elements are required in the boundary method, the demand on

computer memory and on the skill and experience of the user is reduced.

In the case of domain methods, the outer boundaries of the model must be placed sufficiently far away from the excavations in order that errors, arising from the interaction between these outer boundaries and the excavations, are reduced to an acceptable minimum. On the other hand, since boundary methods treat the rock mass as an infinite continuum, the far field conditions need only be specified as stresses acting on the entire rock mass and no outer boundaries are required. The main strength of boundary methods lies in the simplicity achieved by representing the rock mass as a continuum of infinite extent. It is this representation, however, that makes it difficult to incorporate variable material properties and the modelling of rock-support interaction. While techniques have been developed to allow some boundary element modelling of variable rock properties, these types of problems are more conveniently modelled by domain methods.

Before selecting the appropriate modelling technique for particular types of problems, it is necessary to understand the basic components of each technique.

The boundary element method derives its name from the fact that only the boundaries of the problem geometry are divided into elements. In other words, only the excavation surfaces, the free surface for shallow problems, joint surfaces where joints are considered explicitly and material interfaces for multi-material problems are divided into elements. In fact, several types of boundary element models are collectively referred to as the boundary element method. These models may be grouped as follows:

(1)Indirect (Fictitious Stress) method, so named because the first step in the solution is to find a set of fictitious stresses that satisfy prescribed boundary conditions. These stresses are then used in the calculation of actual stresses and displacements in the rock mass.

(2)Direct method, so named because the displacements are solved directly for the specified boundary conditions.

(3)Displacement Discontinuity method, so named because it represents the result of an elongated slit in an elastic continuum being pulled apart.

The differences between the first two methods are not apparent to the program user. The direct method has certain advantages in terms of program development, as will be discussed later in the section on Hybrid approaches.

The fact that a boundary element model extends "to infinity" can also be a disadvantage. For example, a heterogeneous rock mass consists of regions of finite, not infinite extent. Special techniques must be used to handle these situations. Joints are modelled explicitly in the boundary element method using the displacement discontinuity approach, but this can result in a considerable increase in computational effort. Numerical convergence is often found to be a problem for models incorporating many joints. For these reasons, problems, requiring explicit consideration of several joints and/or sophisticated modelling of joint constitutive behaviour, are often better handled by one of the domain methods such as finite elements.

A widely-used application of displacement discontinuity boundary elements is in the modelling of tabular ore bodies. Here, the entire ore seam is represented as a discontinuity which is initially filled with ore. Mining is simulated by reduction of the ore stiffness to zero in those areas where mining has occurred, and the resulting stress redistribution to the surrounding pillars may be examined.

Further details on boundary element methods can be found in the book "Boundary element methods in solid mechanics" by Crouch and Starfield (1983).

New Words and Expressions

1.numerical [nju'merikəl] *a.* 数值的
numerical method 数值方法
2.excavation [ekskə'veiʃən] *n.* 挖掘，挖方
3.dimensional [di'menʃənəl] *a.* 尺寸的
4.fault [fɔ:lt] *n.* 断层，层错
5.intrusion [in'tru:ʒən] *n.* 侵入岩
6.displacement [dis'pleismənt] *n.* 位移
7.boundary method 边界法
8.domain method 域法
9.finite element method 有限单元法
10.finite different method 有限差分法
11.discrete element method 离散单元法
12.hybrid ['haibrid] *n.* 杂交
13.mesh [meʃ] *n.* 网格
14.opening ['əupniŋ] *n.* 开口
15.discretize ['diskri:taiz] *v.* 使离散化
16.continuum[kən'tinjuəm] *n.* 连续体
17.fictitious [fik'tiʃəs] *a.* 假象的，虚设的
18.elongate ['i:lɔŋgeit] *a.* 细长的，拉长的
19.silt [silt] *n.* 淤泥，泥沙
20.convergence [kən'və:dʒəns] *n.* 收敛
21.constitutive ['kɔnstitju:tiv] *a.* 本质的
constitutive behaviour 本构特征
22.tabular ['tæbjulə] *a.* 片状的，薄层的
23. seam [si:m] *n.* 接缝，薄层
24.discontinuity ['dis,kɔnti'nju:iti] *n.* 不连续性，不均匀性

岩体应力分析的数值方法

大多数地下开挖工程的形状是不规则的，并且是成群分布。开挖洞群可形成复杂的三维状态。此外，由于不同的地质特征，如断层和侵入岩体，在相关范围内的岩体特性很少是均一的。因此，闭合的解析解在计算地下洞室围岩体应力、位移和失稳方面有一定的局限性。幸运的是，一系列基于数值分析的计算程序在过去几十年中已经开发完善，并且这些方法成了解决上述问题的手段，能够给出近似解。

在岩石力学中，解决这些问题的应力分析方法分为两类。

边界法，仅在开挖边界划分单元，而岩体内部视为数学意义上的无限连续体。

域法，岩体内部可细分为不同特性的简单的几何单元，并假定每一单元特性是已知的。由这些简单化的结构单元的共性和相互作用来模拟更为复杂的岩体特性。有限单元法和有限差分法就是属于把岩体视为连续介质的域技术。离散单元法可模拟岩体的每一个岩块，把每一个岩块看做单元，也属于域法的一种。

上述两种方法结合构成杂交模型，可以最大限度地利用两方法的优点，并将其缺点限制在最小程度。可以对上述两种方法作一总体对比。域法需要做大量工作在岩体中建

立网格，以便将岩体划分为不同的单元。在复杂模型中，如有多个开挖面，建立网格是非常困难的。在许多模型中，如果有优化的网格生成程序，则建立网格的工作比用手工要简单得多。比较而言，边界元法只要求开挖边界加以离散，把围岩视为无限连续介质。在边界元法中所要求的单元较少，因此对计算机性能、用户的技能和经验要求不高。

对域法而言，模型的外部边界必须远离开挖面，以使得由于外部边界和开挖面的相互影响而产生的误差降低到可以接受的程度。另一方面，由于边界元法把岩体视为无限连续介质，当应力作用整个岩体时，唯一要对远场地质条件详细说明且不要求外边界。边界元法的优势在于把岩体作为连续无限体可以使问题得到简化。然而，由于这种简化，使得把不同岩石的特性和岩石支护作用模型联合起来变得困难。当边界法得到完善时，允许边界上的单元具有不同的岩体性质，用域法解决这类问题比较方便。

对于特殊类型的问题而言，选取相应的模拟技术之前，有必要了解每一种技术的基本要素。

边界单元法是从只对几何边界划分为单元这一事实来命名的。换言之，只有开挖面、浅部开挖的自由面、清楚的节理面、不同材料的界面才可以划分单元。事实上，各种形式边界单元模型集合起来称为边界单元法。这些模式可分为：

(1)间接(虚拟应力)法，之所以如此命名因为在进行解析研究时，首先是找出一组虚拟应力以满足描述的边界条件，然后把虚拟应力用于岩体的真实应力和位移计算。

(2)直接法，这样命名主要考虑在特定边界条件下，把岩体位移直接计算出来。

(3)位移不连续法，这样命名是因为它表示在弹性连续体中有一个拉开的细长缝。

对于程序用户而言，前两种方法的差别并不明显。直接法在程序开发方面有一定的优越性，关于这一点，将在后述的混合法中作一详述。

实际上，边界单元模式扩大到无限远处是有局限性的。如不同种类岩体构成了有限域，不会无限。因此，必须找出特殊的方法来处理这些复杂问题。在边界单元法中，应用位移不连续法使节理得到清楚地模拟，但由此而增加的计算工作量是很大的。对包含多组节理的模型，数值的收敛性也存在一些问题。基于上述原因，对于要求清楚地考虑几组节理或节理结构特性的复杂模式常常用域法如有限元法处理更好。

在层状矿体模型中，广泛应用了位移不连续边界单元法。整个矿体夹层就可视为含有原生矿石的一个不连续体。在采矿区利用减少矿石刚度到零的手段来模拟开采过程，对矿柱周围引起的应力重分布进行检验。

边界单元法的进一步详细研究可参阅 Crouch 等所著的《固体力学中的边界单元法》一书。

Reading Material

Numerical Methods of Stress Analysis of Rock Mass

In practice, the finite element method is usually indistinguishable from the finite difference method; thus, they will be treated here as one and the same. For the boundary

element method, it was seen that conditions on a surface could be related to the state at all points throughout the remaining rock, even to infinity. In comparison, the finite element method relates the conditions at a few points within the rock (nodal points) to the state within a finite closed region formed by these points (the element). The physical problem is modelled numerically by dividing the entire problem region into elements.

The finite element method is well suited to solving problems involving heterogeneous or non-linear material properties, since each element explicitly models the response of its contained material. However, finite elements are not well suited to modelling infinite boundaries, such as occur in underground excavation problems. One technique for handling infinite boundaries is to discretize beyond the zone of influence of the excavation and to apply appropriate boundary conditions to the outer edges. Another approach has been to develop elements for which one edge extends to infinity i.e. so-called "infinity" finite elements. In practice, efficient pre- and postprocessors allow the user to perform parametric analyses and assess the influence of approximated far-field boundary conditions. The time required for this process is negligible compared to the total analysis time.

Joints can be represented explicitly using specific "joint elements". Different techniques have been proposed for handling such elements, but no single technique has found universal favour. Joint interfaces may be modelled, using quite general constitutive relations, though possibly at increased computational expense depending on the solution technique.

Once the model has been divided into elements, material properties have been assigned and loads have been prescribed, some technique must be used to redistribute any unbalanced loads and thus determine the solution to the new equilibrium state. Available solution techniques can be broadly divided into two classes—implicit and explicit. Implicit techniques assemble systems of linear equations that are then solved using standard matrix reduction techniques. Any material non-linearity is accounted for by modifying stiffness coefficients (secant approach) and/or by adjusting prescribed variables (initial stress or initial strain approach). These changes are made in an iterative manner such that all constitutive and equilibrium equations are satisfied for the given load state.

The response of a non-linear system generally depends upon the sequence of loading. Thus it is necessary that the load path modelled be representative of the actual load path experienced by the body. This is achieved by breaking the total applied load into load increments, each increment being sufficiently small, that solution convergence for the increment is achieved after only a few iterations. However, as the system being modelled becomes increasingly non-linear and the load increment represents an ever smaller portion of the total load, the incremental solution technique becomes similar to modelling the quasi-dynamic behaviour of the body, as it responds to gradual application of the total load.

In order to overcome this, a "dynamic relaxation" solution technique was proposed (Otter et al., 1966) and first applied to geomechanics modelling by Cundall (1971). In this

technique no matrices are formed. Rather, the solution proceeds explicitly—unbalanced forces, acting at a material integration point, result in acceleration of the mass associated with the point; applying Newton's law of motion expressed as a difference equation yields incremental displacements; applying the appropriate constitutive relation produces the new set of forces, and so on marching in time, for each material integration point in the model. This solution technique has the advantage that both geometric and material non-linearities are accommodated, with relatively little additional computational effort as compared to a corresponding linear analysis, and computational expense increases only linearly with the number of elements used. A further practical advantage lies in the fact that numerical divergence usually results in the model predicting obviously anomalous physical behaviour. Thus, even relatively inexperienced users may recognise numerical divergence.

Most commercially available finite element packages use implicit solution techniques. For linear problems and problems of moderate non-linearity, implicit techniques tend to perform faster than explicit solution techniques. However, as the degree of non-linearity of the system increases, imposed loads must be applied in smaller increments which implies a greater number of matrix re-formations and reductions, and hence increased computational expense. Therefore, highly non-linear problems are best handled by packages using an explicit solution technique.

New Words and Expressions

1.heterogeneous [ˌhetərəu'dʒiːniəs] *a.* 不均匀的，非均质的

2.negligible ['neglidʒəbl] *a.* 可以忽略的，微不足道的

3.constitutive relation　本构关系

4.matrix ['meitriks] *n.* 母岩，基质，矩阵

5.stiffness ['stifnis] *n.* 刚性(度)，硬度

6.iterative['itərətiv] a. 重复的，反复的，迭代的

阅读材料

岩体应力分析的数值方法

有限单元法和有限差分法通常在实际应用中没有明显差别，可视为同一种方法。对于边界单元法而言，边界面的条件与未开挖岩体所有点甚至到无限远处的状态有关。相对而言，有限单元法与岩体中一些点的条件(典型节点)和这些点所形成的有限闭合域的状态有关。把整体域划分成单元进行数值模拟物理问题。

有限单元法适合解决那些涉及非均质或非线性材料的问题，因为每一单元清楚地表示了其材料的特性。但有限元法并不能很好地解决像地下开挖中遇到的无限边界的问题。处理无限边界的一种方法是把开挖影响带以外的岩体离散，并对外边界施加相应的边界条件；另一种方法是扩充单元，使一边变成无界即所谓无限有限单元。实践中，有效的

前处理和后处理程序允许用户来完成参数分析和接近远场边界条件影响的评估工作。对这一程序所花费的时间与整个分析工作相比是微不足道的。

节理可用专门的“节理单元”来精细地表示。处理这样的单元有不同的建议，但是，没有哪一种单一的方法具有通用性。借助一般的结构关系，可以模拟节理面，但可能会增加计算费用，这和分析技术有关。

一旦模型被划分为单元，材料的性质被赋值，荷载就可以被描述，一些技术必然可用于任何不平衡荷载的重分配，由此来确定新平衡状态的解。有价值的解题方法广泛地分为两类：隐式和显式。隐式法建立线性方程组并用标准矩阵分解技术解线性方程。任何材料的非线性特性可通过修正刚度系数来说明(正割近似值)或用已调整描述的变量(初始应力或初始应变近似值)来确定。这些调整以迭代的形式完成，以便使得所有的基本方程和均衡方程在给定的荷载条件下得到满足。

一般来说，非线性系统反映与加载次序有关。模拟的路径应能代表物体经历的实际加载路径则是必须的。划分总的荷载成为荷载增量以完成这一过程，每一增量要充分的小，那么经过几次迭代增量解的收敛就可完成。由此，被模拟的系统变成增量非线性，荷载增量就变成了总荷载较小部分，增量技术变成类似于模拟物体中拟动态特性，也就表示了总荷载的逐步施加。

为了克服这些问题，Otter 等(1966)提出了“动力松弛”解析技术，并由 Cundall(1971)首次应用到地质力学模拟。不过，该项技术不形成矩阵。然而解析过程却是清晰的，即作用于物体积分点上的不平衡力会引起与这一点有关的物体加速度；利用牛顿(Newton)运动定律来表示差分方程所产生的增量位移；应用相应的结构关系式就会得到一组新的力，这样对模型的每一个材料积分点及时向前推进。这项解析技术有一定的优越性，使结构和材料的非线性都受到调整；相对少量增加的计算成果可与线性分析对比。计算费用与使用的单元数成正比，更加实际的优势在于如下事实，数值离散常常引起模型产生明显的反常物理特性。因此，即使经验不足的用户也能意识到数值存在的离散性。

大多数商用的有限元程序包采用隐式(即矩阵)解析技术。对于线性和适度非线性问题而言，隐式技术比显式的效率高。然而，随着系统非线性程度的提高，施加的荷载必将采用更小的增量，而这些增量暗示着大量矩阵的重组和简化，相应的计算费用也将增加。因此，高度非线性问题最好是利用显式解析技术的软件包来处理。

Unit 20

Text

How Tunnels Are Built

After the general direction for a tunnel has been determined, the next steps are a geological survey of the site and a series of borings to obtain specific information on the strata through which the tunnel may pass. The length and cross section of a tunnel generally are governed by the use for which it is intended, but its shape must be designed to provide the best resistance to internal and external forces. Generally, a circular or nearly circular shapes is choosen.

In every hard rock, excavation usually is accomplished by drilling and blasting. In soft medium-hard rock, a tunnel-boring machine typically does the excavation work. In soft ground, excavation usually is accomplished by digging or by advancing a shield and squeezing the soft material into the tunnel. In all cases, the excavated rock or earth, called muck, is collected and transported out of the tunnel. In underwater tunneling, a shield is used to advance the work. Another method of building an underwater tunnel is to sink tubular sections into a strength dug at the bottom of a river or other body of water.

Hard-rock tunneling Short tunnels through hard rock are driven only from the portals, but longer ones usually are driven also from one or more intermediate shafts. Some long tunnels have been built with the aid of a small pilot tunnel driven parallel to the main tunnel and connected with it by crosscuts at intervals. The pilot tunnel not only furnishes additional points of access but also a route for removing muck and for ventilation ducts and drainage lines.

Another method is the heading-and-bench system, formally used on most large tunnels because it required smaller amounts of power and permitted simultaneous drilling and mucking (removal of excavated material). The upper portion of the tunnel is driven ahead of the lower part which is called the bench. A separate crew is thus able to muck in the lower portion of the tunnel while the upper portion is being drilled.

With improvements in tunneling methods and machinery, the full-face method of attack, previously used only in small tunnels, came into common use in building large ones. This change was partly brought about by the jumbo, a movable platform on which numerous rock drills are mounted. By this device, a large part of the tunnel's face can be drilled at one time. The full face method became the commonest and fastest way to drive a tunnel.

Soft-ground tunneling Some tunnels are driven wholly or mostly through soft material. In very soft ground, little or no blasting is necessary because the material is easily excavated.

At first, forepoling was the only method for building tunnels through very soft ground. Forepoles are heavy planks about 1.5 m long and sharpened to a point. They were inserted over the top horizontal bar of the bracing at the face of the tunnel. The forepoles were driven into the ground of the face with an outward inclination. After all the roof poles were driven for about half of their length, a timber was laid across their exposed ends to counter any strain on the outer ends. The forepoles thus provided an extension of the tunnel support, and the face was extended under them. When the ends of the forepoles were reached, new timbering support was added, and the forepoles were driven into the ground for the next advance of the tunneling.

The use of compressed air simplified working in soft ground. An airlock was built, though which men and equipment passed, and sufficient air pressure was maintained at the tunnel face to hold the ground firm during excavation until timbering or other support was erected.

Another development was the use of hydraulically powered shields behind which cast-iron or steel plates were placed on the circumference of the tunnels. These plates provided sufficient support for the tunnel while the work proceeded, as well as full working space for men in the tunnel.

Under water tunneling The most difficult tunneling is that undertaken at considerable depths below a river or other body of water. In such cases, water seeps through porous material or crevices, subjecting the work in progress to the pressure of the water above the tunneling path. When the tunnel is driven through stiff clay, the flow of water may be small enough to be removed by pumping. In more porous ground, compressed air must be used to exclude water. The amount of air pressure that is needed increases as the depth of the tunnel increases below the surface.

A circular shield has proved to be most efficient in resisting the pressure of soft ground, so most shield-driven tunnels are circular. The shield once consisted of steel plates and angle supports, with a heavily braced diaphragm across its face. The diaphragm had a number of openings with doors so that workers could excavate material in front of the shield. In a further development, the shield was shoved forward into the silty material of a riverbed, thereby squeezing displaced material through the doors and into the tunnel, from which the muck was removed. The cylindrical shell of the shield may extend several feet in front of the diaphragm to provide a cutting edge. A rear section, called the tail, extends for several feet behind the body of the shield to protect workers. In large shields, an erector arm is used in the rear side of the shield to place the metal support segments along the circumference of the tunnel.

The pressure against the forward motion of a shield may exceed 48.8 MPa. Hydraulic jacks are used to overcome this pressure and advance the shield, producing a pressure of

about 245 MPa on the outside surface of the shield.

Shields can be steered by varying the thrust of the jacks from left side to right side or from top to bottom, thus varying the tunnel direction left or right or up or down. The jacks shove against the tunnel lining for each forward shove. The cycle of operation is forward shove ,line, muck ,and then another forward shove. The shield used about 1955 on the third tube of the Lincoln Tunnel in New York City was 5.5 m long and 9.6 m in diameter. It was moved about 81.2 cm per shove, permitting the fabrication of a 81.2 cm support ring behind it.

Cast-iron segments commonly are used in working behind such a shield. They are erected and bolted together in a short time to provide strength and watertightness. In the third tube of the Lincoln Tunnel each segment is 2 m long, 81.2 cm wide, and 35.5 cm thick, and weighs about 1.5 tons. These sections form a ring of 14 segments that are linked together by bolts. The bolts were tightened by hand and then by machine. Immediately after they were in place, the sections were sealed at the joints to ensure permanent watertightness.

Sunken-tube tunnels Where the riverbed subsoil is firm and the river current is not excessive, shore-fabricated tunnel sections can be towed over a prepared trench in the river bottom and sunk into place to form a underwater tunnel. The first major prefabricated, floated, and sunken tunnel was the Detroit River Tunnel between Detroit and Windsor, Ontrio. This vehicular tunnel was built in 1906 ~ 1910. The next important vehicular tunnel built by this method was the Posey Tube, which was completed in 1928. It runs under a saltwater arm between Oakland and Alameda, Calif. Since then many other sunken-tube tunnels have been built under rivers and saltwater bodies, notably the Transbay Tunnel between Oakland and San Francisco.

The cylindrical tunnel sections usually are made of steel in an onshore yard. Each section is about 300 feet (90 meters) long and 28 to 48 feet (8.5 ~ 14.6 meters)in diameter. After the openings at each end of a section are closed with steel bulkheads, the tube is ready for launching in the manner of a ship. Once in the water, a section is ballasted with concrete until a minimum buoyancy is attained. Then the section is towed to the tunnel site. Before the arrival of the section, dredges and underwater excavators dig a trench to the proper depth of the tunnel. When the tube section is positioned precisely over its final location, additional concrete is added until the section sinks into the prepared trench. All sections of the tunnel are transported a sunk in place in the same way.

Each section has projecting plates or flanges that fit over or into the preceding section in the manner of a male and female electrical connection. After one section and a succeeding one have been sunk, divers engage the flanges and tighten the bolts. Steel plates are slid down around the joint between the two closed bulkheads. The joint is then sealed with concrete to ensure watertight links between the sections. After all of the sections are placed and joined, they are covered over with fill to give them stability and protection. Thus the sunken-tube technique is an underwater version of the old cut-and-cover method.

In completing the work, crews enter from the portals at each end of the tunnel and cut away the steel bulkheads as they approach the center of the tube. Concrete then is placed for the interior lining of the tube, providing a good appearance and greater safety. Tiles, duct, linings wiring, pumps, and piping are then added.

New Words and Expressions

1.squeeze [skwi:z] *v.* 挤
2.muck [mʌk] *n.* 出渣
3.section ['sekʃən] *n.* 刃口
4.access ['ækses] *n.* 出入口
5.drainage ['dreinidʒ] *n.* 排水
6.bench [bentʃ] *n.* 台阶
7.ahead of 领先于
8.timber ['timbə] *n.* 原木
9.plank [plæŋk] *n.* 厚板
10.extension [iks'tenʃən] *n.* 延伸
11.airlock ['eəlɔk] *n.* 气塞
12.cast-iron 铸铁
13.crevice ['krevis] *n.* 裂缝
14.exclude [iks'klu:d] *vt.* 隔断
15.diaphragm ['daiəfræm] *n.* 隔板
16.shove [ʃʌv] *v.* 推动
17.shell [ʃel] *n.* 套管
18.rear [riə] *n.* 后部
19.erector [i'rektə] *n.* 升降架
20.steer [stiə] *v.* 向……行驶
21.fabrication [ˌfæbri'keiʃən] *n.* 装配
22.bolt [bəult] *v.* 用螺栓固定
23.subsoil ['sʌbsɔil] *n.* 下层土
24.tow [təu] *vt.* 拖
25.vehicular [vi'hikjulə] *a.* 车辆的
26.arm [ɑ:m] *n.* 支管(线路)
27.segment ['segmənt] *n.* 片
28.crew [kru:] *n.* 人员
29.jumbo ['dʒʌmbəu] *n.* 凿岩钻车
30.platform ['plætfɔ:m] *n.* 台架
31.forepoling ['fɔ:pəuliŋ] *n.* 支撑
32.sharpen ['ʃɑ:pən] *v.* 削尖
33.brace [breis] *n.* 支撑
34.on shore yard 岸上工场
35.bulkhead ['bʌlkhed] *n.* 闷头
36.ballast ['bæləst] *v.* 稳定
37.buoyancy ['bɔiənsi] *n.* 浮动
38.dredge [dredʒ] *n.* 挖掘机
39.projection [prə'dʒekʃən] *n.* 凸出
40.fit [fit] *v.* 装配
41.engage [in'geidʒ] *v.* 着手
42.male [meil] *n.* 插入式配件，凸模
43.female ['fi:meil] *a.* 内孔的，凹形的
44.version ['və:ʃən] *n.* 形式
45.crosscut ['krɔskʌt] *n.* 横巷，正交
46.blast [blɑ:st] *v.* 爆炸
47.inclination [ˌinkli'neiʃən] *n.* 倾斜，倾角
48.shield [ʃi:ld] *n.* 盾
49.pilot ['pailət] *n.* 导洞
50.sunken-tube tunnel 沉管隧道
51.cut-and-cover 挖填隧道

如何建设隧洞

对隧洞来说，总体方向被确定之后，下一步是现场地质测绘和一系列的钻探以获得隧洞通过岩层的各种信息。隧洞的长度和断面形状一般受隧洞用途的控制，但其形状必须设计成所给予的内外阻力最小。一般说来，圆形或近似圆形受到欢迎。

在各种坚硬的岩石中，开挖常用钻探和爆破来完成。在软到中等坚硬的岩石中，一

种专门的隧洞掘进机用于开挖施工。在软岩中，通常利用掘进或先进的盾构来完成开挖，并用盾构把软岩挤入隧洞。在所有的情况下，把开挖的岩石或土(也叫碎屑)收集起来并运到洞外。在地下水位以下隧洞，盾构可提高工作效率。建设地下水位以下的隧洞另一种办法是用沉管刃口进行掘进，这适合于河床和其他有水体的地方。

坚硬岩石隧洞 对于通过坚硬岩石的短隧洞仅从进口开挖，但隧洞较长时可从一个或多个中间斜井开挖。一些长隧洞借助小的导航隧洞建设，而这样导洞和主洞平行，且在一定间距上用横导洞与主洞连起来。这样的导洞不仅增加了出入口，同时为弃渣、通风和排水增加了通道。

另外一种方法是用上导洞和阶梯式开挖，过去常用于大断面隧洞，因为它要求的动力小并且允许钻探和出渣(把开挖材料移走)可同时作业。先开挖上面部分，当上部被钻孔时，施工人员可在下面部分出渣。

随着隧洞开挖方法和机械的改进，受到质疑的全断面开挖(以前在小断面隧洞使用)在建设大断面隧洞中得到普遍使用。这一变化部分来源于凿岩台车的使用，它是在台车可移动平台上安装了数个岩石钻。利用这一装置，一个大的隧洞工作面可进行一次性钻孔。全断面法在隧洞开挖中成为最普遍和进尺最快的方法。

软岩隧洞 一些隧洞全部地或部分地通过软岩石。在这种非常软的岩石中，很少或不需要爆破，因为它很容易被开挖。

最初，矢板是用于软岩建设隧洞的唯一方法。矢板是极重的厚板，大约有 1.5 m 长，端部被削尖。在掌子面它被插入水平撑杆顶部。这样矢板沿着岩面导入且向外倾斜。在所有的顶杆被导入其长度的一半后，放置肋木，它横过顶杆外露端以计量外端的变形。矢板可提供隧洞支撑延展，而矢板下的工作面会膨胀。当矢板到了板的末端，加上新的肋木支撑，为了隧洞下一步进尺，再把矢板沿隧洞面导入。

利用压缩空气可以简化软岩开挖工作。在隧洞内装上气塞孔，人和设备可通过气塞孔，在隧洞工作面气压保持不变，这样在开挖时，使洞室面不致发生破坏，一直到肋木或其他支撑被安装上。

另外一种方法使用液压作为盾构动力，它的后面沿隧洞圆周安装铸铁板或钢板。这样在开挖时钢板对隧洞提供了充分支撑，除此之外在洞内人员有一个充分的工作空间。

水下隧洞 施工最困难的隧洞可以断言是在河流或其他水体以下相当深处。在这种情况下，水会通过孔隙和裂隙渗漏，开挖则是在隧洞以上水位的水压下进行。在硬黏土中开挖隧洞，水量很小，可用水泵抽水。在孔隙发育的地方，用压缩空气方法以隔断水流。随着隧洞深度的增加空气压力也要增加。

对阻止软岩压力来说，圆形盾构大部分是有效的，因而盾构开挖的隧洞是圆形的。盾构一度由钢板和角支撑构成，而且有很重的拉杆隔板横过工作面。隔板上有数个带门的通道，以至于工人在盾构前面可进行开挖。更进一步发展，盾构可以向前推压进入河床泥沙物质中，这样通过门把泥排出并进入隧洞，最后把碎屑泥移走。盾构的圆形套管在隔板前可伸出几英尺以切割隧洞周边。后部或尾部在盾构体后伸延几英尺以保护作业工人。在大的盾构中，在盾构后部沿隧洞周边使用升降臂来装配金属支撑扇形片。

盾构前移所受到的压力会超过 48.8 MPa。液压千斤顶可克服这样大的压力向前推动

盾构，这时在盾构的外表面产生约 245 MPa 的压力。

利用可变推力千斤顶会使盾构行驶，从左到右、从上到下都可做到，这样隧洞可左、右、上、下改变它的方向。每次前移千斤顶要对隧洞衬砌加反力。每次循环是前推、衬砌、出渣，然后是另一次循环。盾构开始应用于 1955 年纽约(New York)城林肯隧洞的第三条管线，其长度 5.5 m，直径 9.6 m。前移一次达 81.2 cm，在其后可装配 81.2 cm 支撑环。

铸铁扇形片在盾构后面隧洞装配中得到普遍使用。把铸铁片在洞内进行装配并用螺栓固定在一起，这样在不长时间内起到加固隧洞和防水作用。在林肯隧洞第三管道，每一扇片长 2 m，宽 81.2 cm，厚 35.5 cm，重大约 1.5 吨。每环有 14 个扇片组成，它们之间用螺栓固定。螺栓是先用手工然后用机械拧紧。在铸铁片被装配后立即对连接处加以封堵以确保永久隔水。

沉管式隧洞　当河床土层胶结，水流不时，在岸上装完的管道可搬运到河床已挖好的沟槽处，并沉入沟槽形成地下管道。第一个大的装配式、浮动的沉管隧道是 Detroit 河隧洞，位于 Detroit 和 Winsor, Ontario 之间。这一车辆隧洞建于 1906 ~ 1910 年之间。用这一方法建成的另一条重要的车辆隧道是 Posey 隧道，于 1928 年完成。它在位于 Oakland 和 Alamed, Calif 间的咸水海湾下运行。从此在河流或咸水体下建了许多沉管式隧道，特别在此要提出的是奥克兰和旧金山之间的 Transbay 隧洞。

在岸上工地，圆筒形管道通常用钢板制成。每条约长 90 m，直径 8.5 ~ 14.6 m。在沟槽开挖后，钢管两端用钢闷头封起来，用船装运准备下水。一旦下水用重混凝土块对钢管加以稳定，直到它受的浮托力最小为止，然后把这一条钢管拖到隧洞的现场。在钢管运到现场前，用挖泥机和水下开挖器开挖沟槽到隧洞适当的深度。当钢管在整个最终位置上精确定位后，增加水泥重块一直把钢管沉到相应的沟槽。其他钢管施工过程是一样的。

每一段凸板或翼缘以凸型或凹型电焊接的形式装入相应的部位。在前一段和其后一段放入水后，潜水员要检查凸缘并拧紧螺栓。在两个合拢闷头间，钢板周围接口要扣好。接口用凝固物封好以确保两段之间连接不漏水。在所有部分被装配和连接好后，再进行填埋使整个管道处于稳定和保护状态。沉管技术是古式切割和掩埋方法的水下形式。

完成这一工作后，工作人员从隧洞的每一端进口进入并切除钢闷头，直到钢管中央处。最后用混凝土做钢管内衬，这样使钢管内壁光滑且更安全。瓦片、导管、套筒导线、水泵、胶管最后组装。

Reading Material

Shields

A tunnel shield is a structural system, normally constructed of steel, used during the face excavation process. The shield has an outside configuration which matches the tunnel. The shield provides protection for the men and equipment and also furnished initial ground support until structural supports can be installed within the tail section of the shield. The shield also provides a reaction base for the breast-board system used to control face

movement. The shield may have either an open or closed bottom. In a closed-bottom shield, the shield structure and skin provide 360-degree ground contact and the weight of the shield rests upon the invert section of the shield skin. The open shield has no bottom section and requires some additional provision to support its weight and the superimposed weight of ground pressure bearing on the skin; normally this provision is a pair of side drifts driven in advance of shield excavation. Rails or skid tracks are installed within these side drifts to provide bearing support for the shield.

Shield length generally varies from 1/2 to 3/4 of the tunnel diameter. The front of the shield is generally hooded so that the top of the shield protrudes forward further than the invert portion; this provides additional protection for the men working at the face and also ease pressure on the breast-boards. The steel skin of the shield may vary from 1.3 to 10 cm in thickness, depending on the expected ground pressures. The type of steel used in the shield is the subject of many arguments within the tunneling fraternity. Some prefer mild steel in the A36 category because of its ductility and case of welding in the underground environment where precision work is difficult. Others prefer a high-strength steel such as T-1 because of its higher strength/weight ratio. Shield weight may range from 5 to 500 tons. Most of the heaviest shields are found in the former Sovier Union because of their preference for cast–iron in both structural and skin elements.

Propulsion for the shield is provided by a series of hydraulic jacks installed in the tail of the shield that thrust against the last steel set that has been installed. The total required thrust will vary with skin area and ground pressure. Several shields have been constructed with total thrust capabilities in excess of 10 000 tons. Hydraulic systems are usually self-contained, air-motor powered, and mounted on the shield. Working pressures in the hydraulic system may range from 20 to 70 MPa. To resist the thrust of the shield jacks, a horizontal structure member (collar brace) must be installed opposite each jack location and between the flanges of the steel set. In addition, some structural provision must be made for transferring this thrust load into the tunnel walls. Without this provision the thrust will extend through the collar braces to the tunnel portal.

An Englishman, Marc Brunel, is credited with inventing the shield. Brunel supposedly got his idea by studying the action of the Teredo navalis, a highly destructive woodworm, when he was working at the Chatham dock yard. In 1818 Brunel obtained an English patent for his rectangular shield which was subsequently uses to construct the first tunnel under the River Thames in London. In 1869 the first circular shield was devised by Barlow and Greathead in London and is referred to as the Greathead-type shield. Later that same year, Beach in New York City produced a similar shield. The first use of the circular shield came during 1869 when Barlow and Greathead employed their device in the construction of the 2.1 m diameter Tower Subway under the River Thames. Despite the name of the tunnel, it was used only for pedestrian traffic .Beach also put his circular shield to work in 1869 to construct

a demonstration project for a proposed New York City subway system. The project consisted of a 2.4 m diameter tunnel, 90 m long, used to experiment with a subway car propelled by air pressure.

Shields are most commonly used in ground condition where adequate stand-up time does not exist. The advantage of the shield in this type of ground, in addition to the protection afforded men and equipment, is the time available to install steel ribs, liner plates, or precast concrete segments under the tail segment of the shield before ground pressure and movement become adverse factors.

One of the principle problems associated with shield use is steering. Nonuniform ground pressure acting on the skin tends to force the shield off line and grade. This problem is particularly acute with closed bottom shield that do not ride on rails or skid tracks. Steering is accomplished by varying the hydraulic pressure in individual thrust jacks. If the shield is trying to dive, additional pressure on the invert jacks will resist this tendency. It is not unusual to find shield wandering several feet from the required. Although lasers are frequently used to provide continuous line and grade data to the operator, once the shield wanders off its course, its sheer bulk resists efforts to bring it back. Heterogeneous ground conditions, such as clay with random boulders, also presents steering problems.

One theoretical disadvantage of the shield is the annular space left between the support system and the ground surface. When the support system is installed within the tail section of the shield, the individual support members are separated from the ground surface by the thickness of the tail skin. When steel ribs are used, the annular space is filled with timber blocking as the forward motion of the shield exposes the individual ribs. A continuous support system presents a different problem. In this case, a filler material, such as pea gravel or grout, is pumped behind the support system to fill the void between it and the ground surface.

The main enemy of the shield is ground pressure. As ground pressure begins to build, two things happen, more thrust is required for shield propulsion and stress increases in the structural members of the shield. Shields are designed and function under a preselected ground pressure. Designers will select this pressure as a percentage of the maximum ground pressure contemplated by the permanent tunnel design. In some cases, unfortunately, the shield just gets built without specific consideration of the ground pressures it might encounter. When ground pressure exceeds the design limit, the shield gets "stuck". The friction component of the ground pressure on the skin becomes greater than the thrust capability of the jacks. Several methods, including pumping bentonite slurry into the skin, ground interface, pushing heavy equipment, and bumping with dynamite, have been applied to stuck shields with occasional success.

Because ground pressure tends to increase with time, the cardinal rule of operation is "keeping moving". This accounts for the fracture activity when a shield has suffered a

temporary mechanical failure. As ground pressure continues to build on the nonmoving shield, the load finally exceeds its structural limit and bucking begins. An example of shield destruction occurred in California in 1968 when two shields being used to drive the Carly V.Porter Tunnel were caught by excessive ground pressure and deformed beyond repair. One of the Porter Tunnel shields was brought to a halt in reasonably good ground by water bearing ground fault that required full breast-boards. While the contractor was trying to bring the face under control, skin pressure began to increase. While the face condition finally stabilized, the contractor prepared to resume operations and discovered the shield was stuck. No combination of methods was able to move it, and the increasing ground pressure destroyed the shield.

To offset the ground pressure effect, a standard provision in design is a cutting edge radius several inches greater than the main body radius. This allows a certain degree of ground movement before pressure can come to bear on the shield skin. Another approach, considered in theory but not yet put into practice, is the "watermelon seed" design. The theory calls for a continuous taper in the shield configuration; maximum radius at the cutting edge and the minimum radius at the trailing edge of the tail. With this configuration, any amount of forward movement would create a drop in skin pressure.

Working decks, spaced 2.4 to 3.0 m vertically, are provided inside the shield. These working decks enable the miners to excavate the face, drill and load blast holes, if necessary, and adjust the breast-board system. The hydraulic jacks for the breast-board are mounted on the underside of the work decks. Blast doors are sometimes installed as an integral part of the work decks if a substantial amount of blasting is expected.

Some form of mechanical equipment is provided on the rear end of the working decks to assist the miners in handling and placing the elements of the support system. In large tunnels, these individual support elements can weigh several tons and mechanical assistance becomes essential. Sufficient vertical clearance must be provided between the invert and the first working deck to permit access to the face by the loading equipment.

New Words and Expressions

1. configuration[kənˌfigju'reiʃən] *n.* 外形
2. breast-board 洞室挡板
3. invert [in'və:t] *n.* 仰拱
4. superimpose ['sju:pərim'pəuz] *v.* 叠合
5. drift [drift] *v.* 滑移
6. hood [hud] *v.* 加盖
7. protrude [prə'tru:d] *v.* 伸出
8. fraternity [frə'tə:niti] *n.* 行会
9. mild [maild] *n.* 软钢，低碳钢
10. preference ['prefərəns] *n.* 选择
11. propulsion [prə'pʌlʃən] *n.* 推进
12. contain [kən'tein] *v.* 控制
13. motor ['məutə] *n.* 发动机
14. member ['membə] *n.* 杆，件
15. brace [breis] *n.* 支柱，联系
16. credit with 认为
17. woodworm 木蛀虫
18. dockyard ['dɔkjɑ:d] *n.* 船厂

19. patent['peitənt] *n.* 专利
20. propel [prə'pel] *v.* 推进
21. precast ['pri:'kɑ:st] *vt.* 预浇制
22. adverse ['ædvə:s] *a.* 不利的
23. steer [stiə] *v.* 驾驶
24. laser ['leizə] *n.* 激光器
25. sheer [ʃiə] *a.* 垂直的
26. heterogeneous [ˌhetərəu'dʒi:niəs] *a.* 不同的
27. boulder ['bəuldə] *n.* 巨砾
28. preselect ['pri:si'lekt] *v.* 预选
29. contemplate ['kɔntempleit] *v.* 计划
30. stuck [stʌk] *n.* 黏性
31. friction ['frikʃən] *n.* 摩阻
32. bentonite ['bentəˌnait] *a.* 膨胀的
33. slurry ['slə:ri] *n.* 稀浆
34. bump [bʌmp] *v.* 冲击
35. cardinal ['kɑ:dinəl] *a.* 基本的
36. frantic ['fræntik] *a.* 狂乱的
37. buck [bʌk] *v.* 顶撞，帽顶
38. halt [hɔ:lt] *v.* 停止前进
39. offset ['ɔ:fset] *v.* 移动，倾斜
40. taper ['teipə] *n.* 圆锥
41. clearance ['kliərəns] *n.* 距离

阅读材料

盾 构

隧洞盾构是一结构系统，通常为钢结构并用于洞室开挖。盾构的外形与隧洞的形状相匹配。盾构可为施工人员和设备提供保护，同时也可提供初始洞室表面支护，这样一直到后部结构支护被安装为止。同时盾构也可用于控制工作面前移的洞室挡板系统，提供反力基座。盾构的底板有敞开式和封闭式。封闭式底板盾构，它的结构和外壳可与洞表面 360° 接触，而盾构的重量置于盾构外壳仰拱上。敞开式盾构没有底板，需要一些辅助设备支撑其重量，地压的合重压在外壳上。一般在盾构前移开挖时，两侧滑移前进。道轨或滑轨的安装不要超过两边的划移线为盾构提供承载支撑。

盾构长一般是隧洞直径的 1/2 ~ 3/4。在盾构的前部加一个盖，以使盾构的顶部向前伸展比仰拱部分大。这样为在工作面处工作的人员提供了保护，同时也减轻了洞室挡板的压力。盾构的钢壳在厚度上的变化范围为 1.3~10 cm，它与预估的地压有关。在盾构中所采用钢的型号在隧洞行业中是一个有争议的课题。一些人认为用 A36 型软钢，因为在地下环境中精确的工作有困难，而这样的钢延性好，易焊接。另外一些人认为用高强度的 T-1 型钢，因为强度重量比较好。盾构重 5~500 t，最重的盾构在前苏联见到过，因为它们在结构和外壳采用了铸铁。

盾构的推动由在盾构尾部安装的多个液压千斤顶来实现，已安装的最后面的钢座对着推力。总推力和盾构外壳的面积、地压有关。几个已组装的盾构总推力超过 10 000 t。在盾构上，液压系统有自控式、空气发动机式和承载式。在液压系统中工作压力范围为 20 ~ 70 MPa。为了得到盾构千斤顶推力的反力，水平结构拉杆(环型支柱)在相对每一个千斤顶位置和钢座凸缘之间必须组装。另外，一些结构性装备也是需要的，以便把推力传给洞壁。没有这样的设备，推力会通过环型支柱扩展达到门架。

英国人 Marc Brunel 被认为是盾构的发明人。据推测当 Brunel 在 Chatham 船场工作

时，他在研究海军船舶船蛆(一种高破坏性木蛀虫)细节时取得盾构的思想。在 1818 年 Brunel 取得了他的矩形盾构英国专利，其后在伦敦泰晤士河(Thames River)下面利用该盾构建成了第一条隧洞。1869 年在伦敦由 Barlow 和 Greathead 设计了第一个圆形盾构，归属于大头型盾构。在这一年稍后时间，Beach 在纽约生产了类似的盾构。圆型盾构的第一次使用是在 1869 年，Barlow 和 Greathead 把他们的装置用于泰晤士河下的塔式地铁建设，直径为 2.1 m。不管隧洞的名称如何，它的使用都是在交通行业。Beach 同样在 1869 年用他的圆形盾构来建设已经论证的纽约地铁系统项目。该工程隧洞直径 2.4 m、长 90 m，并用气压推动地铁卡车做了试验。

盾构在地下环境中得到普遍使用，因为这里不能经受很长时间自稳。在地下，盾构的优势除了保护工作人员和设备外对装配钢肋、衬板在时间上是可行的，或在洞室地压和移动变为不利因素前在盾构尾端下部可浇铸混凝土扇形片。

与盾构使用的主要相关问题之一就是驾驶。不均一地压会作用在外壳上使盾构有离开轨道和坡道的趋势。这一问题对封闭式底板盾构特别突出以致使盾构脱离轨道或滑轨。在单个推力千斤顶上利用可变液压驾驶是可行的。如果盾构准备潜水，在仰拱千斤顶上加压可阻止这一趋势。按要求使盾构穿越几英尺是可行的。虽然使用激光可帮助驾驶者给出轨道和坡度资料，但一旦盾构脱离了它的轨道，它的平衡块会阻止它回到轨道上。在地下不同条件下，如有砾石的黏土也会给驾驶带来问题。

盾构一个理论上的缺陷是在支撑和洞室表面之间会有环行空间。当在盾构尾部安装支撑系统，个别支撑构件由于尾部外壳的厚度会与洞室表面分离开。当采用钢肋时，环行空间要用木块填充，这时盾构前移会使个别钢肋露出来。一个连续的支撑系统也会存在不同问题。在这一情况下，填充料如豆粒石或浆液用泵打到支护系统的后面，以填充支护系统与洞室表面之间的空间。

盾构的主要问题是地压。地压在一开挖就会发生，对盾构会产生两方面的作用：为了盾构推动需更大推力和在盾构结构构件内应力会增加。在预定地压下盾构应设计成能承受得住和达到抵抗地压的作用。设计者所选取的压力应为常规隧洞设计计划最大地压的一个百分值。在一些情况下，不幸的是盾构并没有考虑可能达到的地压就施工了。当地压超过设计值时，盾构会发生“黏住”(stuck)。地压在外壳上的摩擦值要比千斤顶推力值大。为了克服这种情况，可把膨胀岩泥浆打到外壳和岩面之间，并推动它以及用动力冲击盾构都有使被黏住盾构移动的可能。

由于地压会随时间增加，驾驶盾构的基本规则是使其保持“动态”(keeping moving)。如果盾构部分零件有损坏，它们会不规律地晃动。当静止盾构受到的地压不断增加，最终超过其结构极限开始破坏。盾构发生损坏的一个实例是 1968 年在加利福尼亚，这时有两台盾构在 Carly V.porter 隧洞施工，由于过大的地压盾构被埋，且变形超过了使用极限。Porter 隧洞中的一个盾构在一个相当好的地方由于承压水断层作用使其无法前移，要求充填隧洞挡板。当合同商在控制条件下把它带到工作面时，滑板压力开始增加。随着工作面条件趋于稳定，合同商准备恢复施工，发现这时盾构被黏住不动。没有什么方法能移动它，且随地压增加使盾构遭到毁坏。

对倾斜地面压力效应来说，在设计中标准装置切割刃的半径比主体半径大几英寸。

这样压力使盾构外壳承载之前，可允许地面有一定程度的移动。另外一种办法，只是理论上的还没有进入实践，即称“西瓜种”设计。对盾构外形来说，理论上叫“不间断锥”。切割刃半径最大，在尾端的尾刃半径最小。由于这样的外形，任何大小的向前移动均会使外壳压力降低。

在盾构内，在垂直方向上有 2.4 ~ 3.0 m 间距的工作台。这些工作台可用于工人开挖工作面、钻探和装药。如果需要的话，可调整隧洞挡板系统。从隧洞挡板考虑要把液压千斤顶装在工作平台的下面。如果是预裂爆破，作为工作台整体的一部分有时要装一个爆破门。

在工作台的尾部要放一些机械零件，这样有助于工人处理和安装支撑元件。在大型隧洞中，一些支护元件重几吨，用机械作业是必要的。在仰拱和第一工作台之间必须有充分的垂直间距以允许加载设备送到工作面。

附录 1

科技文章翻译和写作指南

一、翻译

(一)翻译标准

对于翻译的标准，比较一致的看法有两条——准确、通顺。“准确”是指要忠实于原作的内容，对原作所述的内容不予增添和删改，同时还要尽力保持原作的文体风格。“通顺”是指译文必须通顺易懂，符合译文语言习惯。这里需要指出的是：“准确”并不是要照搬原文形式，逐字死译，而“通顺”也不是可以随意发挥，忠实于原作和译文通顺两者是统一的。

对于科技作品来说，其特点是叙述原理、传授知识、探讨问题，语言往往简洁明了，结构严谨、逻辑性强，公式、数据和专业术语多，所以对科技作品的翻译必须做到概念清楚，语言通顺，专业术语正确。

举例说明：

例 1　This mineral is no harder than that one.

[误] 这种矿物没有那种矿物硬。

[正] 这种矿物和那种矿物一样软。

可以看出，“准确”是第一位的，译文“准确”对科技作品的翻译来说非常重要。然而，在译文准确的基础上，还应注意译文的通顺。

例 2　What is large and what is small is relative.

[不好] 什么是大的和什么是小的是相对的。

[较好] 大和小是相对的。

(二)翻译过程

翻译过程大体上可以概括为理解和表达两个阶段。理解是指对原作内容要正确地理解，表达是指在译文语言中寻找和挑选恰当的表达方式。

1.长难句

在理解上，最大的问题恐怕是长难句的理解。一般来说，长难句中难点的形成有以下几个方面。

(1)词汇难点：英语中一个词往往可以分属几个词类，在不同的场合或与不同的词搭配时，意义也不相同。因此，在翻译时，首先必须正确选择词义。

(2)语法难点：有的句子除了有主语和谓语外，还有复杂的次要成分，如宾语、定语、状语、独立成分以及各种从句。有的句子有并列成分和几个分句，而分句又带从句，从句本身又带从句。有的句子省略一些成分或者成分倒装，有的有词语分割，不易看出词与词或句与句之间的关系。

2.词汇和语法

在表达上，其难点也不外乎是词汇和语法两个方面。

(1)词汇难点：在翻译过程中，常常会遇到一些词或词组无法直接搬用辞典中的释义，如果勉强按照词典所给的意义译出，译文就会令人费解。在这种情况下，就要在弄清原文词义的基础上根据上下文的逻辑关系以及译文语言的习惯对词义加以引伸，以更确切地表达原文的思想内容。

(2)语法难点：英语和汉语的结构不同，两者不能在形式上相互照搬。尤其在翻译长句时，要按照汉语的习惯，把长句译成短句，并安排好各短句之间的次序。

举例说明：

例 1 The proof that magmatic emanations have passed into such waters is found in the presence in them of such substances as sulphur, arsenic, boric adic, etc., in quantities and under conditions which show that they could not have been leached out from the original rocks of the country.

分析：句中有两个连接词 that。第一个 that 引出同位语从句，把主句 The proof... is found... under conditions 分开，说明 proof； 第二个 that 引导的是一个宾语从句。句中 which 代表前面的复数名词，所以谓语用 show。

译文：该水体含有大量的硫、砷、硼酸等物质，而这些物质不可能是由该区基岩里淋滤出来的。由此证明岩浆喷出物进入了水体。

例 2 The belief that all unconformities are significant punctuation marks in geologic time scale was severely discredited when stratigraphic studies expand into regions where no great breaks are present between systems and where major unconformities are present within previously established systems.

分析：that 引出的同位语从句“that all ... time scale”说明主语 belief 的具体内容，把主句中的主语 belief 同谓语 was discredited 分开。when 引出的时间状语从句又带有两个以 where 引出的定语从句，这两个并列的定语从句用连接词 and 连接起来，用来修饰时间状语从句的名词 regions。从词义上来说，punctuation marks 指标点符号。这里不能直译为标点符号。这样会令人费解，应结合上下文加以引申，译为“分界标志”。同时，break 在这里也要引申为沉积间断。

译文：传统的观念认为所有的不整合都是地质历史上的重要分界标志，而当地层研究延伸到这样一些地区——系与系之间并没有大的沉积间断，但在已确立的系的内部却出现了大的不整合时，这种观念就大大地动摇了。

另外，在翻译的过程中，除了词法、句法外，还要具备一定的专业知识。例如：

例 3 The main thing to notice is that sediments, which once were muds, terminate abruptly against limestone, which once was the main body of the reef.

译文 1：应该注意的一个要点是：过去曾经是淤泥的沉积物，接触到过去曾经是生物礁主体的灰岩时便突然终止了。

分析：“接触到……便突然终止了”这个译文是很难理解的，原因是译文中对 terminate abruptly against 在该句中的确切含义理解不深，缺乏专业知识。这个短语的意思在句中应译为“和……为突变接触”。

译文 2：应该注意的一个要点是，泥质沉积物和由生物礁体形成的灰岩之间为突变

接触。

(三)翻译过程中常见的错误

在翻译过程中常见的错误可以分为两类，即词法和句法两个方面的错误。

1.词法方面的翻译错误举例

汉英两种语言中一词多义和一词多用现象都很普遍，而英语中某个词与汉语中相应的词之间在使用范围和搭配上又有许多差别。因此，在翻译过程中常见的错误之一是词义选择和理解方面的错误。例如：

(1)The research groups constantly had to develop new articles which had never before been produced in the world.

[误] 研究组必须不断发表世界上过去不曾发表过的论文。

[正] 研究组必须不断研制出世界上过去从未制造过的物品。

(2)But for water and air living things could not exist.

[误] 但是生物不可能为了水和空气而生存。

[正] 如果没有空气和水，生物就不能生存。

(3) Lending my dictionary to others is the last thing I want to do.

[误] 借字典给别人是我要做的最后一桩事。

[正] 借字典给别人是我最不愿意的事。

上述例句中的错误是因对 article, but for 和 the last thing 的意义未能正确理解造成的。

(4)墙上有个洞。

[误] There is a hole on the wall.

[正] There is a hole in the wall.

(5)墙上有一幅世界地图。

[误] There is a map of the world above the wall.

[正] There is a map of the world on the wall.

(6)一架梯子靠在墙上。

[误] A ladder is leaning above the wall.

[正] A ladder is leaning against the wall.

汉语表达“在墙上”可以有上述三种不同的英语表达方式。例句(4)中，是因为洞在墙上，所以用 in the wall。例句(5)中，是指挂在墙上，直接接触，所以要用 on the wall。例句(6)中，是指倚靠在墙上，要用 against the wall。

2.句法方面的翻译错误举例

(1)Contrary to what is often thought, the earth does not move round in the empty space.

[误] 与通常的想法相反，地球在空无一物的空间是不运转的。

[正] 与通常的想法相反，地球并不是在空无一物的空间运转的。

(2)This theory of convection currents within the earth is not yet accepted by all geologists.

[误] 所有的地质学家都不赞同这个地球内部存在着对流运动的理论。

[正] 并非所有的地质学家都赞同这个地球内部存在着对流运动的理论。

以上两个例句是由于不了解英汉两种语言表达否定方式的不同而造成的。在英语中否定谓语，译成汉语应否定状语，等等。

(3)看到这张地形图时，她的心往下一沉，简直站不住了。

[误] When she looked at the topographic map, her heart sank and could hardly stand.

[正] When she looked at the topographic map, her heart sank and she could hardly stand.

在例句中，her heart 可以作 sank 的主语，但不能作 could hardly stand 的主语，因此必须在连接词 and 后加主语 she，才符合逻辑。

(四)长难句的分析及译法

英语中有些长句的结构比较复杂、层次重叠，理解和翻译时有一定难度，故许多译者把这样的句子俗称长难句。长难句之所以长而难，主要是因为这种句子在简单的基本句型上经过了不同程度的扩展和变化。这种扩展和变化的方式很多，它可以是增加句子的修饰成分(定语或状语)、并列成分或附加成分(插入语、同位语或独立成分)，也可以是由各种短句或从句来充当句子中的某些成分，甚至短语和从句本身又具有短语和从句，从而形成多级短语和多级从句。此外，还可出现句子倒装和省略以及词或句子之间的分隔现象等变化，从而使句子的意思不易理解并难以简明、确切表达。为了帮助初学译者解决这一难点，下面简要介绍长难句的一般分析方法和译法。

1.长难句分析的一般步骤与方法

(1)遇到长难句时，先通读全句，确定专业术语和各种词组的词义，然后分析句子的主要成分——主语和谓语。

(2)分析句型，看这个句子是简单句还是复合句，对复合句要根据连接词或关联词弄清是并列复合句还是主从复合句。

(3)分析句中主要扩展成分，包括所有的短语和从句的类型及其充当的成分，注意辨析句中的分词、动名词和谓语动词。

(4)分析句中次要扩展成分或附加成分，如插入语、同位语或其他独立成分，确定它们所修饰的对象及与句中主要成分的关系。

(5)综合分析句中各种成分之间的相互关系，可用图解或划线的方法把相关成分联系起来，注意是否存在有倒装、省略或分隔现象。

(6)通过对全句的词义确定和语法分析并结合上下文和专业内容准确理解原意后，按中文表达习惯译成汉语。

2.长难句的分析举例

1)扩展的简单句的分析例解

(1)A comparison of the map indicating the centers of major earthquakes with the one showing the location of the world's active volcanoes demonstrates some of the similarities in their distribution.

分析:

①这个简单句的主要成分主语是 comparison，谓语是 demonstrates。

②扩展成分为介词短语和分词短语，均起定语作用，即主语 comparison 带两个介词

短语 “of... earthquakes” 和 “with...volcanoes”，每个介词短语又各带有一个分词短语 (“indication...” 和 “showing...”)，每个分词短语再各带一个介词短词(“of major earthquakes”和“of the world’s active volcanoes”)；宾语带一个二级介词短语。

③句中的不定代词 one 代替前面出现过的名词 map。

译文：

把标有主震震中的地图与表示世界上活火山位置的地图进行对比，就可以看出它们的分布有某些相似之处。

(2)Indirect evidence of the existence of life in the Precambrian is furnished by huge volumes of calcareous materials in ancient limestones and marbles, of carbon in graphite deposits, and of enormous Precambrian sedimentary iron ore deposits.

分析：

①这个简单句的主语为 evidence，谓语为 is furnished，本句为一被动语态句。

②扩展成分：主语 evidence 带一个多级介词短语；huge volumes 后跟有三个并列介词短语即 “of calcareous... marbles”，“of carbon... deposits” 和 “of enormous... deposits”。

③ “huge volumes”为 “大量” 之意，为使译文明确，可重复与三个并列介词短语一起译出。

译文： 古代石灰岩和大理岩中的大量石灰质物质、石墨矿床中大量的碳以及大量的前寒武纪沉积铁矿床，提供了前寒武纪存在生命的间接证据。

2)长难复合句的分析例解

(1)The rocks beneath are folded or tilted: they may be metamorphased and intruded by lava; they contain different fossils; they do not conform or fit in with the younger rocks resting on them; their surface is weathered and eroded.

分析：

①这是一个并列复合句，由五个分句构成，彼此被分号分开。

②在第四个分句中，fit with 是动词短语，与 conform 共用 with，with 不再重复。此处 or fit in (with)是进一步附加说明前一短语动词的意思，根据具体情况，可不单独译出。

③为使译文简练，分句中的主语代词不必一一译出。

译文：

下面岩层已经褶曲，也可能已经变质：其中有熔岩侵入；含有不同的化石；与上覆的新岩层不整合；有一个风化剥蚀面。

(2)They(the folds) are known as anticlines or upfolds, when the beds are bent upward as in an arch; as synclines or downfolds. When the beds sink into a trough; as monoclines when the fold has only a single slope, joining the ground raised from its continuation on a lower level; as isoclines when the folds have been so pressed together that the summits have been forced over so that both sides of the fold slope in the same direction.

分析：

①本句由四个并列关系的复合句组成，其中每一个复合句都有一个由 when 引出的时间状语从句。

②后三个复合句中的主句，在引导补语的 as 之前都省略了主语和谓语(“they are known”)。

③将这类并列复合句译成中文时，各原分句中相同的主语可视具体情况不必一一译出。

译文：

当岩层向上弯曲呈拱形时，它们(这种褶皱)就被称为背斜或隆褶皱；当岩层下弯而呈凹槽形时，就叫做向斜或槽褶皱；当褶皱只有一个斜层，而且这个斜层又与从较低的位置延续上来的地面相接，就叫做单斜；当几个褶皱一起受挤压，以致它们的顶部被过度的推挤，因而褶皱的两翼均向同一方向倾斜时，就叫做等斜褶皱。

(3)The historical geologist will tell you approximately when the first forms of life developed, what kinds of plants and animals lived during each period, and when man may have made his appearance on the earth.

分析：

①这是一个带有三个并列宾语的主从复合句。主句的主语是 The historical geologist，谓语是 will tell。

②三个并列的宾语从句分别依次由“when, what 和 when”引出，前二者由逗号分开，后二者由连接词 and 连接并在它之前由逗号分开。

③句中的 approximately 修饰主句的谓语，不是修饰 when 引导的从句。

④“ and ”连接句子时，往往不译成中文，连接词和词组时须译成中文。

译文：

地史学家会大致地告诉你，最初的生物种类是在什么时期进化的，每个纪都生存过何种动植物，大概什么时期地球上出现了人类。

(4)Since one of the critical differences between minerals and rocks is that minerals are approximately homogeneous substances, and most rocks are not, this means that one piece of quartz will be about as hard as another piece, that it will have the same specific gravity, and if formed in a similar environment, it will have about the same crystal form.

分析：

①这是一个较复杂的主从复合句，主句的主语是 this，谓语是 means，带一个原因状语从句(“since...not,”)和三个并列的宾语从句，即依次为“that ...piece”，“that...gravity”和 “and if ...form” 。

②原因状语从句位于主句前，带有两个并列的表语从句，即“that ... substances”和“and most... not” 。

③第三个宾语从句又带一个条件状语从句“if... environment”，其中在 if 和 formed 之间省略了 it is。

译文：

由于矿物同岩石的一个重要区别在于矿物是近乎均质的物质，而大部分岩石则不是，因此这就意味着，每块石英的硬度大致相同、比重相同，而且如果是在相似的环境中形成的话，还会有大致相同的晶形。

(5)In many such ranges, complex masses made up of cherty sedimentary rocks, peridotite, serpentinite, and tholeiite pillow lavas—an assemblage precisely like the materials dredged from the Mid-Atlantic Ridge and exposed on St. Pauls Rocks —are all jumbled together as though stirred in a giant mixing bowl, to form a melange.

分析：

①这是一个有分隔和省略现象的复杂主从复合句，主句的主语是 masses，谓语是 are jumbled，二者相隔很远。这种分隔是由于主语后面有修饰语。分词短语“made up of lavas”为 masses 的定语，两个破折号内有 masses 的同位语 assemblage。而“like the materials”这一介词短语是 assemblage 的后置定语。“dredged from...Ridge”和“exposed on ... Rocks”两个分词短语都是修饰 materials 的后置定语。

②as though 引出的方式状语从句省略了 they had been。

③“to form a melange”不定式短语作目的状语，说明主句的谓语。

译文：

在许多这种山脊里，由燧石沉积岩、橄榄岩、蛇纹岩以及拉斑玄武岩的枕状熔岩组成的一套复杂岩体(极像从大西洋中脊取出而暴露在圣保罗罗克斯的一套物质)，就好像在调拌食品的大碗里经过搅拌似的，全都混杂在一起而成混杂岩。

3)长难句的译法

翻译长难句时，首先要抓住全句的中心内容，弄清句子由几部分构成，它们之间存在什么样的语法关系，同样要特别注意单词、短语、从句的并列层次和扩展层次；然后根据汉语的表达习惯予以重新安排，不要过分拘泥于原文的结构形式。长难句的译法一般有三种，即顺译法、逆译法和分译法。现举例说明如下：

(1)顺译法——按照原文的上下层次顺序而译。

How these two things—energy and matter behave, how they interact one with the other, and how people control them to serve themselves make up the substance of two basic physical sciences, physics and chemistry.

能和物质这两种东西如何起作用，它们如何相互影响，人们如何控制它们使之为自己服务，这些问题构成两门基础自然科学——物理和化学的主要内容。

In fact, the generally accepted theory now is that the production of rain depends upon the presence of dust particles in the air, which serve as nuclei about which the drops may form.

事实上，目前普遍公认的理论是：雨的形成依赖于空气中尘粒的存在，因为尘粒可作为晶核，使雨珠在其周围生成。

(2)逆译法——改变原文叙述层次，由下而上逆序而译。

The method normally employed for free electrons to be produced in electron tubes is thermionic emission, in which advantage is taken of the fact that, if a solid body is heated sufficiently, some of the electrons that it contains will escape from its surface into the surrounding space.

固体被加热到足够温度时，它所含的电子就会有一部分离开表面飞逸到周围空间中去，这种现象叫做热电放射。通常，电子管就是利用这种现象来产生自由电子的。

(3)分译法——把与主句内容联系不很紧密的从句或分词短语译成若干短句。

Many sedimentary rocks contain such features as ripple marks, exactly like those we can see forming in sediments at the bottom of present-day lakes or shallow seas.

我们可以看到，现在的湖底或海底部的沉积物中形成了波痕。许多沉积岩都含有类似这种波痕的特征。

Coal of the highest rank, called anthracite, occurs in certain localities where unusually high pressure due to deep burial and subsequent earth movements, combined with a moderate increase of temperature, has facilitated the driving-off of nearly all the volatile constitutes.

最高牌号的煤叫做无烟煤，生成于这样的地区，即那里由于埋藏很深以及后来的地壳运动而产生的异乎寻常的高压，同适当增加的温度相结合，促使几乎所有的挥发物质排除掉。

二、写作

(一)总体要求

科技论文摘要，不论用中文或英文，均应在正文之前，简明扼要地介绍论文的内容，说明研究的目的、方法、研究成果和最终结论。

书写科技论文英文摘要时应注意如下几点：

(1)要具有独立性，它是可以独立使用的一篇短文，其内容应保持论文报告的基本信息和格调。国外有的学术刊物规定摘要为 1 000 个印刷符号或 300~500 个单词。国内各大学术刊物杂志一般要求 300~500 个印刷符号即可。

(2)应以第三人称书写，避免用第一人称作主语，因为使用第一人称往往具有个人感情色彩。

(3)英文摘要中出现俄、德、法、日等其他国家的人名时，应将它译成英文，不要夹杂使用。而中国的地名、人名均用汉语拼音字母书写。

(4)应避免使用公式、化学结构式、图表、参考文献标记、符号和人们不熟悉的缩写字。

(5)应与中文摘要内容一致，译文确切，无语法错误，并应注意包含 3~8 个外文关键词(key words)。

(二)论文题目的英译(Title Writing)

1.英文摘要题目的写作

英文摘要题目的写作应注意以下几点：

(1)题目中除冠词、介词和连词外，其余所有实词的第一个字母都应大写。当介词、冠词在题目的开头时第一个字母也应大写。有些刊物规定题目的所有字母都大写。题目一般不超过 20 个字。在一行不够书写时，可分成两行，此时第二行的第一个字的第一个字母必须大写。

(2)科技论文题目通常不加标点符号，也不使用引号，但允许使用破折号。

(3)题目一般不必用完整的句子，大多数应该用名词短语，力求简、明、短。

2.标题常用的英译形式

为了使科技论文题目的英译工作规范化，现将几种常见的固定表达格式列举如下。

(1)××××××的研究

A Study on...

The Study of ...

A Study of the...

(2)××××××的初步研究

Preliminary Study of...

(3)××××××的新进展

Recent Advances in...

(4)××××××的探讨

Exploration on...

A Study of...

Study on...

Investigation on...

(5)××××××的应用

The Application of ...

Application of...to...

(6)××××××的方法及其应用

Method of...and its Application

(7)××××××的几个问题

Some Problems of

(8)××××××的讨论

Discussions on...

(9)××××××简介

A Brief Description of...

(10)××××××的现状和今后的发展趋势

Present and Future Trends in (of)...

3.作者与工作单位的译法

论文题目后写明作者全名及所在单位。作者姓名英译应按1958年2月11日第一届人大第五次会议上批准的《汉语拼音方案》的拼音字母正确书写。现在我国规定姓在前，名在后，姓和名的第一个字母均应大写，名中的第一、第二个字中间不必用短划线分隔。例如，吴勇强，应写为 Wu Yongqiang，不要写成 Wu Yong-qiang，也不要按欧美习惯写成 Yongqiang Wu。作者的姓名应在题目下面居中书写。作者的工作单位另起一行写。工作单位应从小至大依次书写，在高等院校工作，最基层单位可写至系；在厂矿、研究所，可写上厂矿及研究所名即可，不必再细分至教研室、科、室。下面给出几个不同的实例。

例 1 A Study on...(标题)

Su Pu

Department of Geology, Shanxi Mining College, China

例 2 Recent Advances in...(标题)

Wu Yongqiang

Geological Institute, The Chinese Academy of Sciences, China

例 3 Preliminary Study...(标题)

Lei Fang

Yong Dingzhuang Colliery, Datong Bureau of Mines, China

(三)论文摘要主题句(Topic Sentences of Abstracts)

论文摘要主题句常在摘要的开头。许多论文摘要常用一些固定的句式，现将常见的句式列出，以供参考。

(1)In this paper the author deals with ...(本文研究了)

(2)In this paper the author analyses...(本文分析了)

(3)In this paper the author discusses...(本文讨论了)

(4)In this paper the author proposes...(本文提出了)

(5)In this paper the author introduces...(本文介绍了)

(6)In this paper the author presents...(本文给出了)

(7)In this paper the author studies and analyses...(本文研究和分析了)

(8)In this paper the author describes...(本文描述了)

......

也可以将以上一些句子用下列被动语态来表达，例如：

(1)...is discussed in this paper

(2)...is studied

(3)...is proposed...

(四)科技论文英文摘要的时态(Tenses of Abstracts)

英文论文摘要中的动词时态反映研究过程中各种事实的时间关系，现将主要时态的一般原则归纳如下。

1.现在时态

概述一般结论、真理、实验结果、方法描述，都用一般现在时表述。例如：

(1)A method is presented for calculating...

(2)The advantage offered by the method and scope of its application is outlined.

(3)A series of examples for plate tectonics are analyzed...

2.过去时态

实验经过、过去的研究工作、一些特定结论要用过去时态。例如：

(1)The plate tectonic theory was first proposed by...

(2)The structural analyses were carried out with...

(3)The results were compared with...

3.现在完成时态

叙述从某一时间开始，对现在有影响，用现在完成时态，例如：

(1)His results have never been published.

(2)Up to now, our main natural energy sources have been coal and oil.

(3)Since World War II, the use of the fast electronic computers has made...

4.一般将来时态

叙述今后研究及打算，预期的结果要用一般将来时，例如：

(1)The results will be discussed further.

(2)Some experiments will be carried out later.

(3)The conclusion will be proved ...

(五)结尾句(Concluding Sentences)

在英文摘要的结尾往往需写上作者的结论或建议。下面是一些常见的句式：

(1)It is suggested that...

(2)It is recommended that...

(3)The results show that...

(4)The results suggest that...

(5)The author concludes that ...

(六)英文摘要关键词(Key words)

英文摘要的最后，附有关键词(Key words)。关键词是论文的主题词，也是论文的精华。一般是将能反映论文中心议题的词和词组列出若干个(10 个以内)，直接写在 Key words 之后，词与词之间用分号分开，最后一个词后面，可不加标点。例如：

Key words: lithosphere; hydrosphere; atmosphere; crust

关键词应力求简明、扼要，尽量选拔能体现论文主题思想的文字，不要拖泥带水。

以上仅是撰写英文摘要的一般程序，供初次写作者参考。当然，随着英语水平的提高及写作技巧的不断熟练，完全可以不拘泥上述形式，只要能抓住论文的中心以简练的语言综合扼要地概述即可。

(七)英文摘要实例

为了掌握英文摘要的写作格式和要领，下面列举几个英语论文摘要的实例。

例 1　Plate Tectonic Reconstructions of the Cretaceous and Cenozoic Ocean Basins

CHRISTOPHER R. SCOTESE[1], LISA M. GAHAGAN[2] and ROGER L. LARON[3]

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2. *The Department of Geological Sciences, The The University of Texas, Austin, TX* 78713 (*U. S. A*)

and The Institute for Geophysics, The University of Texas, Austin. TX 78759 (*U. S. A*)

3. *School of Oceanography, University of Rhode Island, Kingston, RI* 02881 (*U. S. A*)

Abstract

In this paper the author present nine reconstructions for the Mesozoic and Cenozoic, based on previously published sea-floor spreading isochrons. The purpose of this study was① to determine if the isochrons could be refitted to produce accurate plate tectonic reconstructions, ② to identify areas of further investigations, and ③ to test the capabilities and accuracy of interactive computer graphic methods of plate tectonic reconstruction. In general, Tertiary and Late Cretaceous isochrons could be refitted with little overlap and few gaps; however, closure errors were apparent in the vicinity of the Bouvet and Macquarie triple junctions. It was not possible to produce Early Cretaceous reconstructions that were consistent with the previously published isochrons. In this paper the author also propose that the Late Cretaceous and Early Tertiary plate reorganizations observed in the Indian ocean were the result of the progressive subduction of an intra-Tethyan rift system.

例 2 **COAL MEASURES OF AN OROGENIC RECESS: LATE PERMIAN SYDNEY BASIN, AUSTRALIA**

J. GILBERT JONES, PATRICK J. CONAGHAN and KEVIN L. McDONNELL

School of Earth Sciences, Macquarie University, North Ryde, N. S. W. 2113 (Australia)

Abstract

Comparison of the Late Permian northeastern Sydney Basin with the Pliocene-Quaternary "Purari recess" of the Papuan Basin on the basis of gross lithology and lithologic sequence. Sediment provenance, sedimentary environment and basin architecture confirms its tectonic context as an orogenic recess of closely similar character. This comparison, together with comparison to the Late Carboniferous Aappalachian Basin of Pennsylvania, suggests that, under favourable climatic circumstances, orogenic recesses are optimum sites for thick coal accumulation.

例 3 **Discovery of Blake Reversed Episode in China**

Liu Chun

Paleomagnetic Laboratory, Institute of Geology, Chinese Academy of Sciences, Beijing

Abstract

A reversed polarity event known as Blake Episode is first found at the Xujiayao Paleolithic site, Shanxi province, China.

This discovery has an important significance for further studying geomagnetic reversals during the Brunhes chron and the evolution of biological species.

In this paper, the Quatenary geology and chronology related to the Blake Episode are briefly discussed.

Key words: blake; brunhes; reversed episode; paleolithic site

附录 2

生词表

A

a general rule of thumb　经验法则
abrasion [ə'breiʒən] *n.* 磨蚀(作用)
abutment [ə'bʌtmənt] *n.* 桥台，支座
acceleration [æk,selə'reiʃən] *n.* 加速(度)，加快
access ['ækses] *n.* 出入口
accessibility [,ækəsesi'biliti] *n.* 易接近
accommodate [ə'kɔmədeit] *v.* 适应
account for　说明，证明
acquisition [,ækwi'ziʃən] *n.* 获得，获得物
activity [æk'tiviti] *n.* 活性
adit ['ædit] *n.* 坑道，平洞，入口
adjacent [ə'dʒeisənt] *a.* 邻近的，接近的
admixture [əd'mikstʃə] *n.* 混合，混合物，掺合物
adverse ['ædvə:s] *a.* 不利的
aerial ['ɛəriəl] *a.* 航空的
aerial photograph　航摄照片
Afghanistan [æf'gænistæn] *n.* 阿富汗
agent ['eidʒənt] *n.* 营力，作用力
aggregate ['ægrigeit] *n.* 集料，骨料，集合体
agitation [ædʒi'teiʃən] *n.* 搅动
agronomist [ə'grɔnəmist] *n.* 农学家
ahead of　领先于
airlock ['eəlɔk] *n.* 气塞
alignment [ə'lainmənt] *n.* 准线，校正
allowable stress　允许应力
alluvial [ə'lu:vjəl] *a.* 冲积的，冲积土的
along with　同时
alongside [ə'lɔŋsaid] *prep.* 靠在……旁边
aluminum [ə'lju:minəm] *n.* 铝
amphibole ['æmfibəul] *n.* 闪石
analogous [ə'næləgəs] *a.* 类似的
analogy [ə'nælədʒi] *n.* 类比，类似
anchor ['æŋkə] *n.* 锚杆，绞钉
andesite ['ændizait] *n.* 安山岩
angle ['æŋgl] *n.* 角，看法
angular ['æŋgjulə] *a.* 棱角状的
anion ['ænaiən] *n.* 阴离子
annular ['ænjulə] *a.* 环的，环状的
anomaly [ə'nɔməli] *n.* 反常，异常
anticline ['ænti,klain] *n.* 背斜
aphanitic [,æfə'nitik] *a.* 非显晶(质)的，隐晶(质)的
aqueous ['eikwiəs] *a.* 水的，含水的
aqueous system　水系统，含水体系
arch [ɑ:tʃ] *n.* 拱，拱形物
arching ['ɑ:tʃiŋ] *n.* 弓状结构，拱架
arid ['ærid] *a.* 干燥的
arm [ɑ:m] *n.* 支管(线路)
arrangement [ə'reindʒmənt] *n.* 排列
as well as　既……又
ascending [ə'sendiŋ] *a.* 向上的
ash fall　灰尘沉降，火山灰沉降
asperity [æs'periti] *n.* 粗糙度，不平滑
asphaltic mastic　沥青树脂
assembly [ə'sembli] *n.* 组合，装配
assorted [ə'sɔ:tid] *a.* 各式各样的
asymmetrically [,æsi'metrikəli] *adv.* 不对称地
at an angle　倾斜地，成一定角度
at intervals　每隔一段时间(距离)
at the base of　在……基部
auger ['ɔgə] *n.* 麻花钻，土钻，钻孔机

aureole ['ɔ:riəl] *n.* 接触变质带
authority [ɔ:'θɔriti] *n.* 当局，官方
avalanche ['ævə,lɑ:nʃ] *n.* 雪崩
axial plane 轴平面

B

back-analysis 反分析
bail [beil] *n.* 钩，卡箍
ballast ['bæləst] *v.* 稳定
bar [bɑ:(r)] *n.* 条钢，铁条
barren ['bærən] *a.* 贫瘠的
basalt ['bæsɔ:lt] *n.* 玄武岩
base [beis] *n.* 碱
basin ['beisn] *n.* 盆地
batholith ['bæθəliθ] *n.* 岩基
be applied to 应用于
be called upon to 被用来
be concerned with 关心
be defined as (被)定义为
be expressed as (被)表达为
bedding ['bediŋ] *n.* 层理，层面，基床
bedding plane 层理面，层面
bedrock ['bedrɔk] *n.* 基岩，岩床，底岩
bench [bentʃ] *n.* 台阶
bentonite ['bentə,nait] *a.* 膨胀的
benzene ['benzi:n, ben'zi:n] *n.* 苯
beryl ['beril] *n.* 绿玉，绿柱石
bind [baind] *n.* 结合；*v.* 捆，绑
blanket ['blæŋkit] *n.* 覆盖层，毯子
blast [blɑ:st] *v.* 爆炸
blend [blend] *vt.* 混合
block [blɔk] *v.* 截断，封锁
block diagram 方框图
blow [bləu] *n.* 打击；*v.* 吹
blowout ['bləu'aut] *n.* 井喷，爆炸
body wave 体波
bolt [bəult] *n.* 螺栓；*v.* 用螺栓固定
bond [bɔnd] *n.* 粘结，胶结
bore [bɔ:] *v.* 开挖，钻孔
bored pile 钻孔桩
bottom ['bɔtəm] *vt.* 测量……深浅；*n.* 底
boulder ['bəuldə] *n.* 漂砾，巨砾，圆卵石
boulevard ['bu:livɑ:d] *n.* <美>林荫大道
bounce [bauns] *v.* (使)反跳，弹起
boundary method 边界元法
brace [breis] *n.* 支柱，联系
bracket ['brækit] *n.* 分类
Brazil [brə'zil] *n.* 巴西
break loose 塌岩堆
breakage ['breikidʒ] *n.* 破坏，破损
breakdown ['breikdaun] *n.* 破坏，崩溃
breast-board 洞室挡板
brittle ['britl] *a.* 易碎的，脆弱的
brittleness ['britlnis] *n.* 脆性，脆度
broad [brɔ:d] *a.* 概括的
buck [bʌk] *v.* 顶撞，帽顶
buckle ['bʌkl] *n.* 纵弯曲；*v.* 弯曲，褶皱
build up 增进，增大
bulbous['bʌlbəs] *a.* 球形的
bulk solution 本体溶液
bulkhead ['bʌlkhed] *n.* 闷头
bump [bʌmp] *v.* 冲击
buoyancy ['bɔiənsi] *n.* 浮动
bureau [bjuə'rəu] *n.* 局，科，处
buttress ['bʌtris] *n.* 支撑墩；*vt.* 支持
by convention 按照惯例
by-product 副产品

C

cable ['keibl] *n.* 钢索，锚索
caisson ['keisən] *n.* 沉箱
calcite ['kælsait] *n.* 方解石
calcium ['kælsiəm] *n.* 钙
calcium silicate 硅酸钙
calculus ['kælkjuləs] *n.* 微积分学
campfire ['kæmp ,fair] *n.* 营火

cantilever ['kæntili:və] *n.* 悬臂
canyon ['kænjən] *n.* 峡(深)谷
capillarity [kæpi'læriti] *n.* 毛细管作用
capita ['kæpitə] (caput 的复数) *n.* 头
cardinal ['kɑ:dinəl] *a.* 基本的
cartridge ['kɑ:tridʒ] *n.* 夹头
cast-iron 铸铁
cation ['kætaiən] *n.* 阳离子
cause [kɔ:z] *n.* 原因，起因
cave [keiv] *v.* 坍陷
cement [si'ment] *n.* 水泥，接合剂
cementation [ˌsi:men'teiʃən] *n.* 胶结
cementitious [ˌsimen'tiʃiəs] *a.* 似水泥的
centipoise ['sentipɔiz] *n.* 百分之一泊(黏滞性单位)，厘泊
cfs 立方英尺/每秒
chain [tʃein] *n.* 链，山脉
chamber ['tʃeimbə] *n.* 室
characterize ['kæriktəraiz] *vt.* 刻画，具有……特征
charged ion 带电离子
charged species 带电粒子
check-list (核对用)清单
chemical attack 化学侵蚀
chip [tʃip] *n.* 碎屑物
chloride ['klɔ:raid] *n.* 氯化物
chunk [tʃʌŋk] *n.* 厚块
circuitous [sə(:)'kju(:)itəs] *a.* 绕行的，迂回的，间接的
civil engineer 土木工程师
clarify ['klærifai] *v.* 澄清，阐明
classic ['klæsik] *a.* 第一流的，经典的
classification [ˌklæsifi'keiʃən] *n.* 分类，分级
clearance ['kliərəns] *n.* 距离
coarse-grained ['kɔ:s'greind,'kours-] *a.* 粗粒的
cobble ['kɔbl] *n.* 鹅卵石，中砾石
coefficient [kəui'fiʃənt] *n.* 系数，折算率
cohesive [kəu'hi:siv] *a.* 有结合力的
coincide [ˌkəuin'said] *vi.*(点,面积等)(与……)相合；(时间)(与……)相同；与……一致(with)
colluvial [kə'lu:viəl] *a.* 崩积的
commence [kə'mens] *v.* 开始
compact ['kɔmpækt] *v.* 压实，压密
comparable ['kɔmpərəbl] *a.* 类似的，可比的
comparative [kəm'pærətiv] *a.* 相当的，比较的
compass ['kʌmpəs] *n.* 罗盘，指南针
composite ['kɔmpəzit, -zait] *n.* 合成物
compressional [kəm'preʃ(ə)nəl] *a.* 压缩性的，与压缩有关的
compressive [kəm'presiv] *a.* 有压缩力的，综合性的
compressive stress 压应力
concave [kɔn'keiv] *a.* 凹形的
concentration [ˌkɔnsen'treiʃən] *n.* 浓度
concise [kən'sais] *a.* 简明的，扼要的
conclusive [kən'klu:siv] *a.* 确实的，最后的，决定性的
cone [kəun] *n.* 锥
confer with 与……商量
configuration [kənˌfigju'reiʃən] *n.* 外形
confine ['kɔnfain] *v.* 限制，约束
confining pressure 封闭压力，围压
conjunction [kən'dʒʌŋkʃən] *n.* 连接，连系
consolidate [kən'sɔlideit] *v.* 加固
consolidation [kənˌsɔli'deiʃən] *n.* 固结
consolidation settlement 固结沉降
constant of proportionality 比例常数
constitutive ['kɔnstitju:tiv] *a.* 本质的
constitutive relation 本构关系
construct [kən'strʌkt] *vt.* 绘[编]制，作(图)，建造
contain [kən'tein] *v.* 控制
contaminant [kən'tæminənt] *n.* 致污物，

污染物

contemplate ['kɔntempleit] *v.* 计划

context ['kɔntekst] *n.* 前后关系，关联

continuum[kən'tinjuəm] *n.* 连续体

contract ['kɔntrækt, kən'trækt] *v.* 收缩

contractor[kən'træktə] *n.* 承包商

convergent [kən'vəːdʒənt] *a.* 会聚性的，收敛的

convergence [kən'vəːdʒəns] *n.* 收敛

convergent plate boundary 会聚板块边界

conversion [kən'vəːʃən] *n.* 转化，转变

convey [kən'vei] *vt.* 搬运

core [kɔː] *n.* 岩心，地核

corroboratory [kə'rɔbərətəri] *a.* 证实的

corrosion [kə'rəuʒən] *n.* 腐蚀，侵蚀

counterpart ['kauntəpɑːt] *n.* 副本，对应物

covalent [kəu'veilənt] *a.* 共有原子价的，共价的

covalent bond 共价键

crack [kræk] *n.* 裂缝

crater ['kreitə] *n.* 陨石坑，火山口

credence ['kriːdəns] *n.* 信任，证件

credit with 认为

creep [kriːp] *n.* 蠕变，滞缓

crest [krest] *n.* 颠值，峰值

crevice ['krevis] *n.* 裂缝

crew [kruː] *n.* 人员

crop out (岩石、矿石等)露在地面，显露出来

crosscut ['krɔskʌt] *n.* 横巷，正交

cross-section 横断面

cross-sectional ['krɔs'sekʃənəl] *a.* 横向的

crosswise ['krɔswaiz; (*US*) 'krɔːs-] *a.* 交叉的，横的

crush [krʌʃ] *vt.* 压碎，碾碎

crystalline ['kristəlain] *a.* 晶质的

crystalline solid 结晶固体

crystallize ['kristəlaiz] *vi.* 结晶

cube [kjuːb] *n.* 立方体，立方

cubic ['kjuːbik] *a.* 立方体的，立方的

cumulative ['kjuːmjulətiv] *a.* 累积的，渐增的

current ['kʌrənt] *n.* 流

curvature ['kəːvətʃə] *n.* 弯曲，曲率

curvilinear [kəːvi'liniə(r)] *a.* 曲线的；*n.* 曲线

customarily ['kʌstəmərəli;ˌkʌstə'merəli] *adv.* 通常

cut [kʌt] *v.* 切割；*n.* 开采

cut-and-cover 挖填隧道

cutoff [kʌtɔf] *n.* 切开

cylinder ['silində] *n.* 圆柱，圆筒，柱面

D

Darcy equation 达西公式

datum ['deitəm] *n.* data 的单数，数据，资料，基准(点，面)

decompose [ˌdiːkəm'pəuz] *v.* 分解

deform [diː'fɔːm] *v.* 使变形，畸变，畸形

deformation [diːfɔː'meiʃən] *n.* 变形

deformation modulus 变形模量

degradation [ˌdegrə'deiʃən] *n.* 破坏，裂解，降低

dehydration [ˌdiːhai'dreiʃən] *n.* 脱水

delineate [di'linieit] *vt.* 刻划，画轮廓，描写

deltaic [del'teiik] *a.* 三角洲的，三角形的

demarcation [ˌdiːmɑː'keiʃən] *n.* 界线，界限，分界

demonstrate ['demənstreit] *v.* 论证，证明

density ['densiti] *n.* 密度

derivative [di'rivətiv] *n.* 导数，微商

designate ['dezigneit] *vt.* 指定(出示)，标明

destabilize [diː'steibilaiz] *vt.* 使动摇

detachment [di'tætʃmənt] *n.* 分离

deteriorate [di'tiəriəreit] *v.* 使恶化，弄坏

detrital [di'traitəl] *a.* 碎屑的，由岩屑形成的

detritus [di'traitəs] *n.* 碎屑，岩屑，碎石，砂砾
dewater [di:'wɔ:tə] *v.* 排水，抽水
diagonally [dai'ægənli] *adv.* 对角地
diagrammatic [ˌdaiəgrə'mætik] *a.* 图表的，概略的
diagrammatic sketch 示意图
diaphragm ['daiəfræm] *n.* 隔板
die out 逐渐消失
differential [ˌdifə'renʃəl] *n.* 差别，差异
dike [daik] *n.* 岩墙，岩脉
dilation [dai'leiʃən] *n.* 膨胀，扩大(展)
dilute [dai'lju:t, di'l-] *a.* 稀释的
dimensional [di'menʃənəl] *a.* 尺寸的
dimensionless [di'menʃənlis] *a.* 无因次的
diorite ['daiərait] *n.* 闪长岩
dip [dip] *n.* 倾向；*v.* 倾斜
dipping bed 倾斜层
discontinuity ['disˌkɔnti'nju:iti] *n.* 不连续性，不均匀性
discrete element method 离散单元法
discretize ['diskri:taiz] *v.* 使离散化
disintegrate [dis'intigreit] *vt.* (使)分解，(使)碎裂
dislodge [dis'lɔdʒ] *vt.* 移动，挪动
dispel [dis'pel] *v.* 驱散，驱除，消除
displace [dis'pleis] *vt.* 取代，置换
displacement [dis'pleismənt] *n.* 位移
dissipate ['disipeit] *v.* 消散，分散，扩散
dissociate [di'səuʃieit] *v.* 分离，游离
dissolution [disə'lju:ʃən] *n.* 溶解(作用)
distressing [distresiŋ]*a.* 令人苦恼的
disturbance [dis'tə:bəns] *n.* 断裂，损伤
divergent [dai'və:dʒənt] *a.* 扩张的
diversion [dai'və:ʃən] *n.* 导流
divert [di'və:t] *v.* 使转向，分(引)水
dockyard ['dɔkjɑ:d] *n.* 船厂
domain method 域法
dome [dəum] *n.* 圆顶，穹窿
dosage ['dəusidʒ] *n.* 剂量，用量
doubly['dʌbli] *adv.* 两倍地，双重地
dowel ['dauəl] *n.* 销钉，钢筋
downslope *a.* 下坡的
drainage ['dreinidʒ] *n.* 排水，排泄
drastic ['dræstik] *a.* 激烈的，猛烈的
drawdown ['drɔ:daun] *n.* 下降，降落
dredge [dredʒ] *n.* 挖掘机
drift [drift] *v.* 滑移
drill [dril] *n.* 钻孔，凿片，训练
ductile ['dʌktail] *a.* 延性的，韧性的，黏性的
ductility [dʌk'tiliti] *n.* 和易性
duly ['dju:li] *adv.* 适当地
dump [dʌmp] *vt.* 倾倒，倾卸
duty ['dju:ti] *n.* 荷载
dye [dai] *v.* 染色，着色
dynamo-thermal ['dainəməu'θə:məl] *a.* 动热的

E

Earth-fill 土坝
effective stress 有效应力
elaborate [i'læbərət] *a.* 详尽的
elastic [i'læstik] *a.* 弹性的
elastic rebound theory 弹性回弹说
electrical charge 电荷
electrolyte [i'lektrəulait] *n.* 电解，电解质，电解液
electroosmosis [iˌlektrəuɔs'məusis] *n.* 电渗
electrostatic [i'lektrəu'stætik] *a.* 静电的，静电学的
elevation [ˌeli'veiʃən] *n.* 海拔，高程
elliptical [i'liptikəl] *a.* 椭圆的
elongate ['i:lɔŋgeit] *v.* 拉长，(使)伸长，延长；*a.* 细长的，拉长的
elsewhere ['els'hwɛə] *adv.* 在别处

embed [im'bed] *v.* 埋置，嵌入
empirical [em'pirikəl] *a.* 经验的，实验的
encasing [in'keisiŋ] *n.* 砌壁
encompass [in'kʌmpəs] *v.* 包括，包围，环绕
end product 最后产物
engage [in'geidʒ] *v.* 着手
enrich [in'ritʃ] *vt.* 使富足，使肥沃
epicenter ['episentə(r)] *n.* 震中
equation[i'kweiʃən] *n.* 方程式，等式
equilibrium [ˌi:kwi'libriəm] *n.* 平衡，均衡
equivalent [i'kwivələnt] *a.* 相等的，相当的，等效的
equivalent charge 当量电荷
erector [i'rektə] *n.* 升降架
erode[i'rəud] *v.* 冲刷，侵蚀
erosion [i'rəuʒən] *n.* 侵蚀(作用)
eruption [i'rʌpʃən] *n.* 爆发，喷发
escalate ['eskəleit] *n.* 逐步升级，逐步升高
evaluate [i'væljueit] *vt.* 对……估价，对……作评价
evaluation [iˌvælju'eiʃən] *n.* 估价，评价
ever-present ['evəˌprezənt] *a.* 总是存在的
excavate ['ekskəveit] *v.* 挖掘，开挖
excavation [ekskə'veiʃən] *n.* 挖掘，挖方
exclude [iks'klu:d] *vt.* 隔断
exert[ig'zə:t] *vt.* 施加(压力等)
exfoliation [eksˌfəuli'eiʃən] *n.* 页状剥落
exhaustive [ig'zɔ:stiv] *a.* 消耗的，使枯竭的
experimentally [iksperi'mentəli] *adv.* 实验上，用实验方法
explosive [iks'pləusiv] *a.* 爆炸性的，爆发性的
exposure [iks'pəuʒə] *n.* 暴露，出露
extension [iks'tenʃən] *n.* 延伸
extract [iks'trækt] *vt.* 提炼出，分离出

F

fabrication [ˌfæbri'keiʃən] *n.* 装配
factor ['fæktə] *n.* 系数，因素
fault [fɔ:lt] *n.* 断层，层错
fault metamorphism 断层变质作用
feasibility [ˌfi:zə'biləti] *n.* 可行性，可能性
feldspar ['feldspɑ:] *n.* 长石
felsic ['felsik] *n.* 长英质的(矿物)
female ['fi:meil] *a.* 内孔的，凹形的
ferromagnesian [ˌferəumæg'ni:ʃən] *a.* 含有铁镁的
ferrum ['ferəm] <拉> *n.* 铁
fibre ['faibə] *n.* 纤维
fictitious [fik'tiʃəs] *a.* 假象的，虚设的
fine aggregate 细骨料
fine-grained ['fain'greind] *a.* 有细密纹理的
finite different method 有限差分法
finite element method 有限单元法
fit [fit] *v.* 装配
flake [fleik] *n.* 薄片
flatten ['flætn] *v.* 变平，变单调
flexible ['fləuti] *a.* 柔软的，有弹性的
float [fləut]*n.* 漂流，飘移
floating ['fləutiŋ] *a.* 浮动的
flotation [flə'teiʃən] *n.* 漂浮，浮力
flow line 流线
flow net 流网
flow path 流径，流动通道
flute [flu:t] *n.* 凹槽，螺丝槽
foam [fəum] *n.* 泡沫，水沫
fold [fəuld] *n.* 褶皱
fold geometry 褶皱的几何形态
foliation [ˌfəuli'eiʃən] *n.* 叶理，剥理
footing ['futiŋ] *n.* 底座
force potential 势
forcibly['fɔ:səbəli] *adv.* 强制地
foregoing [fɔ:'gəuiŋ] *a.* 以上的

forepoling ['fɔːpəuliŋ] *n.* 支撑
formalise ['fɔːməlaiz] *vt.* 使定形
formation [fɔː'meiʃən] *n.* 群，系
former glacier　古冰川
formula ['fɔːmjulə] *n.* 公式
formula weight　式量，化学式量，分子量
fraction['frækʃən] *n.* 分数
fracture ['fræktʃə] *v.* (使)破碎，(使)破裂
fragile ['frædʒail] *a.* 损坏的
fragment ['frægmənt] *n.* 碎屑，碎片
frantic ['fræntik] *a.* 狂乱的
fraternity [frə'təːniti] *n.* 行会
freezing point　凝固点，凝固温度
friction ['frikʃən] *n.* 摩擦，摩阻
friction angle　内摩擦角
frost [frɔst, frɔːst] *n.* 霜，霜冻
fugacity [fju(ː)'gæsiti] *n.* 逸性，逸度
fume [fjuːm] *n.* 烟尘，气体

G

gabbro ['gæbrəu] *n.* 辉长岩
gelifraction [ˌdʒeli'frækʃən] *n.* 融化泥流
generic [dʒi'nerik] *a.* 一般的，普通的
geologic setting　地质构造
geomechanics [ˌdʒi(ː)əumi'kæniks] *n.* 地质力学
geometrical [dʒiə'metrik(ə)l] *a.* 几何的，几何学的
geothermal [ˌdʒi(ː)əu'θəməl] *a.* 地热的，地温的
glacial ['gleisjəl, 'glæs-] *a.* 冰的，冰河的
glacier ['glæsjə, 'gleiʃə] *n.* 冰河，冰川
goethite ['gəuθait] *n.* 针铁矿
grab ['græb] *n.* 抓斗，开挖机
graded bed　粒级层，递变层
gradient ['greidiənt] *n.* 梯度
grain shape　晶粒形状
grain size　粒度，颗粒尺寸
gram [græm] *n.* 克
grand [grænd] *a.* 重大的，主要的
granite ['grænit] *n.* 花岗岩
granodiorite [ˌgrænəu'daiəˌrait] *n.* 花岗闪长岩
granular ['grænjulə] *a.* 颗粒的，颗粒状的
graphic ['græfik] *a.* 图解的，绘图的
graphically ['græfikəli] *adv.* 用图表表示
gravel ['grævəl] *n.* 砾石，卵石
gross [grəus] *n* 总(毛)重，全体，总数
ground water　地下水，潜水
grout [graut] *n.* (灰，砂，水泥)浆；*vt.* 灌浆
guideline ['gaidˌlain] *n.* 方针，指南
Gulf Coast　墨西哥湾岸区
gunite ['gʌnait] *n.* 压力喷浆
gusty ['gʌsti] *a.* 阵风的，起大风的
gypsum ['dʒipsəm] *n.* 石膏

H

halite ['hælait] *n.* 岩盐
halt [hɔːlt] *v.* 停止前进
hammer ['hæmə] *n.* 锤
handful ['hændful] *n.* 一把，一撮
hardened ['hɑːdənd] *a.* 坚硬的，坚毅的
hardpan ['hɑːdpæn] *n.* 硬土层
haulage ['hɔːlidʒ] *n.* 运输，巷道
havoc ['hævək] *n.* 大破坏，毁坏
heading ['hediŋ] *n.* 水平巷道，导洞，掌子面
headroom ['hedruːm] *n.* 顶空间
heave [hiːv] *v.* 水平移动，举起
heel [hiːl] *n.* 脚跟，坝踵
hematite ['hemətait] *n.* 赤铁矿
heterogeneity [ˌhetərəudʒi'niːiti] *n.* 不均匀
heterogeneous [ˌhetərəu'dʒiːniəs] *a.* 不同种类的，非均质的
hieroglyphic [ˌhaiərə'glifik] *n.* (*pl*) 象形文字
hinge [hindʒ] *n.* 铰链，枢纽
hinge line　枢纽线，铰合线

homogeneous [ˌhɔməu'dʒiːnjəs] *a.* 均质的
hood [hud] *v.* 加盖
hopper ['hɔpə] *n.* 漏斗
horseshoe ['hɔːsʃuː] *n.* 马蹄形
hose[həuz] *n.* 软管，胶皮管
hospitable ['hɔspitəbl] *a.* 有利的
humidity [hjuː'miditi] *n.* 湿度
humus ['hjuːməs] *n.* 腐殖质
hybrid ['haibrid] *n.* 杂交
hydrated sheath 水化层
hydration [hai'dreiʃən] *n.* 水合，水合作用
hydraulic [hai'drɔːlik] *a.* 与水有关的，水力的，水压的
hydraulic conductivity 渗透系数
hydraulic gradient 水力梯度
hydraulically [hai'drɔːlikli] *adv.* 水力学地
hydraulics ['hai'drɔːliks] *n.* 水力学
hydrocarbon [ˌhaidrəu'kɑːbən] *n.* 烃，碳氢化合物
hydrogen ['haidrəudʒən] *n.* 氢
hydrogeologist *n.* 水文地质学家，水文地质工作者
hydrologic [hai'drɔlədʒik] *a.* 水文(学)的
hydrolysis [hai'drɔlisis] *n.* 水解(作用)
hydrostatic [ˌhaidrəu'stætik] *a.* 静水力学的，流体静力学的
hydrothermal metamorphism 热液变质
hydroxide [hai'drɔksaid] *n.* 氢氧化物
hypocenter ['haipəusentə(r)] *n.* 震源

I

igneous ['igniəs] *a.* 火成的
immediate settlement 瞬时沉降
impart [im'pɑːt] *v.* 赋予，告知
impede [im'piːd] *v.* 阻碍，妨碍
impervious [im'pəːvjəs] *a.* 不能渗透的
impervious to water 防水的，不透水的
implication [ˌimpli'keiʃən] *n.* 含意，暗示
imprint [im'print] *n.* 盖印
simultaneous [ˌsiməl'teinjəs] *a.* 同时的，同时发生的
in effect 有效
in place (安装)就位，安装好，在原位
in relation to 关于
in the case of 在……的情况
in the light of 根据，按照，鉴于
in the terms of 就……而论，在……方面
inaccessibility [ˌinækˌsesə'biliti] *n.* 不易接近，难达到
incipient [in'sipiənt] *a.* 原始的，最初的
incise [in'saiz] *v.* 切割，蚀刻
inclination [ˌinkli'neiʃən] *n.* 倾斜，弯曲，倾角，倾向
incline [in'klain] *n.* 斜面，倾向，倾斜
inclined bed 倾斜层
incompressible [ˌinkəm'presəbl] *a.* 不能压缩的
inconsistent [ˌinkən'sistənt] *a.* 不协调的
incorporate [in'kɔːpəreit] *v.* 结(联)合，合并
increasingly [in'kriːsiŋli] *adv.* 日益，愈加
incredibly [in'kredi'bili] *adv.* 不可思议地
indices [ˌindisiːz] index 的复数
indisputable [ˌindis'pjuːtəbl] *a.* 无可争辩的
individual mineral 单个矿物，单矿物
induce [in'djuːs] *vt.* 促使，导致，引起
infiltrate [in'filtreit] *v.* 渗透，渗入
ingest [in'dʒest] *vt.* 摄取，咽下
injection [in'dʒekʃən] *n.* 注射，喷射
inorganic [ˌinɔː'gænik] *a.* 无生物的，无机的
insert [in'səːt] *vt.* 插入，嵌入，引入
insight ['insait] *n.* 洞悉，理解
insight into 洞察
in-situ 现场
insofar as 据，就……(来说)
insolubility [inˌsɔlju'biliti] *n.* 不溶性
instantaneous [ˌinstən'teinjəs] *a.* 瞬间的，

即刻的
interaction [ˌintər'ækʃən] *n.* 交互作用，交感
intercept [ˌintə'sept] *n.* 截距
interlock [ˌintə'lɔk] *v.* 互锁，连结
intermediate [ˌintə'mi:djət] *a.* 中间的
intermitcent pier 间隔板
interrelate [ˌintə(:)ri'leit] *v.* (使)相互关连
intrinsic permeability 渗透率
intrusion [in'tru:ʒən] *n.* 侵入岩
invariant [in'vɛəriənt] *n* 不变式，不变量
invert [in'və:t] *n.* 仰拱；*v.* 颠倒，倒转，使反向
ion ['aiən] *n.* 离子
ion sheath 离子覆盖，离子层
iron ['aiən] *n.* 铁
isotope ['aisəutəup] *n.* 同位素
issue ['isju:] *n.* 问题
iterative['itərətiv] *a.* 重复的，反复的，迭代的

J

jam [dʒæm] *vt.* 挤进，使塞满
joint [dʒɔint] *n. vt.*节理，接缝，连接
jumble ['dʒʌmbl] *v.* 混合，掺杂
jumbo ['dʒʌmbəu] *n.* 凿岩钻车

K

kaolinite ['keiəlinait] *n.* 高岭石
kilobar ['kiləubɑ:] *n.* 千巴(气压单位)
kinetic [kai'netik] *a.* 动力(学)的，反应动力学的

L

lag [læg] *n.* 迟延
laminar['læminə(r)] *a.* 层理的，成层的，薄层的
lamination [ˌlæmi'neiʃən] *n.* 层压(成型)，纹理
laser ['leizə] *n.* 激光器
lava ['lɑ:və] *n.* 熔岩，火山岩
lava flow 熔岩流
lay bare 揭开
layered rock 层状岩石
leaflike [li:flaik] *a.* 像叶子的，成薄片的
leakage ['li:kidʒ] *n.* 渗漏
leap [li:p] *v.* 跳过，跃过
lettuce ['letis] *n.* 莴苣，生菜
level ['lev(ə)l] *n.* 水准仪；*vi.* 变平，拉平
limb [lim] *n.* 翼，分支
limestone ['laimstəun] *n.* 石灰岩
limonite ['laiməˌnait] *n.* 褐铁矿
line of equal potential 等势线
lining ['lainiŋ] *n.* 衬砌
lithification [ˌliθifi'keiʃən] *n.* 成岩作用
lithostatic ['laiθəu'stætik] *a.* 静岩的，岩石静压力的
load-bearing capacity 承载能力
load-bearing value 承载值
log [lɔg] *v.* 记录
longitudinal [lɔndʒi'tju:dinl] *a.* 纵向的
Louisiana [lu(:)ˌi:zi'ænə] *n.* 路易斯安那(美国州名)

M

mafic ['mæfik] *n.* 镁铁质的，镁铁的
magma ['mægmə] *n.* 岩浆
magma chamber 岩浆空间
magnesium [mæg'ni:zjəm] *n.* 镁
magnitude ['mægnitju:d] *n.* 量，大小，幅度
maintenance ['meintinəns] *n.* 维持，维护
male [meil] *n.* 插入式配件，凸模
manage ['mænidʒ] *v.* 经营
manometer [mə'nɔmitə] *n.* 压力计
mantle ['mæntl] *n.* 覆盖层，地幔
map [mæp] *v.* 测绘，绘制
margin ['mɑ:dʒin] *n.* 余量(额，地)，页边

marginally ['mɑːdʒɔnəli] *adv*. 在一定程度上
markedly [mɑːktli] *adv*. 显著地， 明显地
masonry ['meisnri] *n*. 砖石结构
mass [mæs] *n*. 物质
mass flow 质量流(量)
Mat foundation 筏板基础
matrix ['meitriks] *n*. 母岩，基质，矩阵
mean[miːn, min] *a*. 平均的
meander [mi'ændə] *v*. 蜿蜒而流
measure ['meʒə] *n*. 量度，测量
mechanically [mi'kænikəli] *adv*. 机械地
media ['miːdjə] *n*. (medium 复数)介质
medium['miːdjəm] *n*. 媒介物，介质
member ['membə] *n*. 杆，件
Memphis 孟菲斯(古城)
mesh *n*.网格
metallic [mi 'tælik] *a*. 金属的
metamorphic [ˌmetə'mɔːfik] *a*. 变质的
metamorphism [ˌmetə'mɔːfizəm] *n*. 变质，变质作用
metamorphose [ˌmetə'mɔːfəuz] *vt*. 使变形[质]
meteoric [ˌmiːti'ɔrik] *a*. 流星的，疾速的
meteorite ['miːtjərait] *n*. 陨星，陨石
mica ['maikə] *n*. 云母
micaceous [mai'keiʃəs] *a*. 云母状的
Michigan ['miʃigən] *n*. 密歇根州(美国州名)
migration [mai'greiʃən] *n*. 迁移，流动
mild [maild] *n*. 软钢，低碳钢
millidarcy ['milidɑːsi] *n*. 毫达西
mining ['mainiŋ] *n*. 开矿，采矿，开采
Minnesota [ˌmini'səutə] *n*. 明尼苏达州(美国州名)
minus ['mainəs] *a*. 负的，减去的
mix [miks] *n*. 混合料，配合比
mobilise ['məubilaiz] *vt*. 动员，调动
model ['mɔdl] *n*. 模型
Mohr failure envelope 莫尔破坏包络线
molar ['məulə] *a*. 摩尔的，重量摩尔的，重模的
molarity [məu'læriti] *n*. 摩尔浓度
mole['məul] *n*. 摩尔，克分子(量)
molecule ['mɔlikjuːl, 'məu-] *n*. 分子
moment ['məumənt] *n*. 力矩，动量
monitor ['mɔnitə] *n*. 监测
montmorillonite [ˌmɔntəmə'riləˌnait] *n*. 蒙脱石
monument ['mɔnjumənt] *n*. 纪念碑
mortar ['mɔːtə] *n*. 灰浆
mosaic [mɔ'zeiik] *n*. 镶嵌状的
motion ['məuʃən] *n*. 运动，动作
motor ['məutə] *n*. 发动机
muck [mʌk] *v*. 出渣
mudflow ['mʌdfləu] *n*. 泥流
mudstone ['mʌdstəun] *n*. 泥岩
multiphrase ['mʌltifeiz] *a*. 多相的
multiply ['mʌltipli] *vt*. 乘，使相乘
multipurpose ['mʌlti'pəːpəs] *a*. 多功能的
multistory [ˌmʌltis'tɔːri] *a*. 多层的
muscovite [ˌmʌskə'vait] *n*. 白云母

N

name for 与(另一人)同名
nature ['neitʃə] *n*. 特性
necessitate [ni'sesiteit] *v*. 使成为必要
negligible ['neglidʒəbl] *a*. 可以忽略的，微不足道的
nested ['nestid] *a*. 嵌套的
nonaqueous ['nɔn'eikwiəs] *a*. 非水的
nonelectrolyte ['nɔni'lektrəulait] *n*. 非电解质
nonhomogeneous ['nɔnˌhɔmə'dʒiːnjəs] *a*. 非均质的
nonideal ['nɔnai'diəl] *a*. 非理想的

nonionic ['nɔnai'ɔnik] *a.* 在溶液中不分解成离子的
nonpolar ['nɔn'pəulə] *a.* 无极的
northerly ['nɔːðəli] *a.* 北方的，来自北方的
notation [nəu'teiʃən] *n.* 记号，标志
nozzle ['nɔzl] *n.* 管口，喷嘴
numerical [nju'merikəl] *a.* 数值的
Nurek Dam 努列克大坝
nut [nʌt] *n.* 螺帽，螺母

O

obelisk ['ɔbilisk] *n.* (埃及的)方尖塔(碑)，方尖碑形物
obsidian [ɔb'sidiən] *n.* 黑曜岩
occurrence [ə'kʌrəns] *n.* 出现，存在
ocean wave 海浪
octagonal [ɔk'təgənal] *a.* 八角形的
offset ['ɔːfset] *n.* 移动，倾斜；*vi.* 偏移
olivine [ˌɔli'viːn] *n.* 橄榄石
on shore yard 岸上工场
Ontario [ɔn'tɛəriəu] *n.* 安大略湖
ooze [uːz] *v.* 渗出，慢慢流出
opening ['əupniŋ] *n.* 开口
ore [ɔː(r)] *n.* 矿石
ore deposits 矿床
organic [ɔː'gænik] *a.* 有机的
organic contaminant 有机污染物
outcrop ['autkrɔp] *n.* 露头，露头岩
outlet ['autlet, -lit] *n.* 出口
oxidation [ɔksi'deiʃən] *n.* 氧化

P

paleontological [ˌpæliɔn'tɔlədʒikəl] *a.* 古生物学的
panel ['pænl] *n.* 面板
partial pressure 分压
particle ['pɑːtikl] *n.* 颗粒，微粒
parts per billion 十亿分率，十亿分之几
parts per million 百万分率，百万分之几
passage ['pæsidʒ] *n.* 通道，通路
passive support system 被动支护系统
patent ['peitənt] *n.* 专利
pathway ['pɑːθwei] *n.* 路径，通道(路)
pattern ['pætən] *n.* 模式，形式
peat [piːt] *n.* 泥炭(土)
pebble ['pebl] *n.* 卵石，石子
pegmatite ['pegmətait] *n.* 结晶花岗岩，花岗伟晶岩
penetrate ['penitreit] *vt.* 穿透
peninsula [pi'ninsjulə] *n.* 半岛
penstock ['penstɔk] *n.* 压力钢管，进水管
percolation [ˌpəːkə'leiʃən] *n.* 渗透
peridotite [ˌperi'dəutait] *n.* 橄榄岩
periphery [pə'rifəri] *n.* 周围
permeability [ˌpəːmiə'biliti] *n.* 渗透性
perpendicular [ˌpəːpən'dikjulə] *a.* 垂直的，正交的
pertinent ['pəːtinənt] *a.* 有关的，相干的，中肯的，贴切的
petroleum [pi'trəuliəm] *n.* 石油
phaneritic [fænə'ritik] *a.* 显晶岩的
phyllite ['filait] *n.* 千枚岩
pick up 选取
piezometer [ˌpaiə'zɔmitə] *n.* 压力，测压管
pile cap 桩帽
pilot ['pailət] *n.* 导洞
pioneer [ˌpaiə'niə] *v.* 为……开路， 开拓
plagioclase ['pleidʒiəukleis] *n.* 斜长岩
plain [plein] *n.* 素混凝土
planar ['pleinə] *a.* 平面的，平坦的
plank [plæŋk] *n.* 厚板
platform ['plætfɔːm] *n.* 台架
plot [plɔt] *n.* 情节，图
plug [plʌg] *n.* 插头
plunging fold 倾伏褶皱
plutonic [pluː'tɔnik] *a.* 深成的，火成的

(岩石)
pneumatic [nju(:)'mætik] *a.* 气动的
pneumatically [nju(:)'mætikli] *adv.* 有空气作用地
polar ['pəulə] *a.* 极性的
pop [pɔp] *vt.* 爆裂
pore [pɔ:, pɔə] *n.* 小孔，气孔
pore water 孔隙水
poresity [pɔ:'rɔsiti] *n.* 孔隙率，孔隙度
porous ['pɔ:rəs] *a.* 多孔的
porphyritic [ˌpɔ:fi'ritik] *a.* 斑状的
portal ['pɔ:təl] *n.* 入口
pose [pəuz] *v.* 形成，引起
postulate ['pɔstjuleit] *vt.* 假设，假定
potassium [pə'tæsjəm] *n.* 钾
potent ['pəutənt] *a.* 有力的，有效的
pozzolan ['pɔtsəulɑ:n] *n.* 火山灰
precast ['pri:'kɑ:st] *a.* 预制的；*vt.* 预浇制
precautionary [pri'kɔ:ʃənəri] *a.* 预防的
precede [pri(:)'si:d] *v.* 领先，优先，在……之前
precipitate [pri'sipiteit] *vt.* 使沉淀(出)，析出
precipitation [priˌsipi'teiʃən] *n.* 降雨量
predetermine ['pri:di'tə:min] *vt.* 预定
preexist [ˌpri:ig'zist] *v.* 先前存在
preference ['prefərəns] *n.* 选择
preliminary [pri'liminəri] *a.* 初始的，初步的，预先的
prerequisite ['pri:'rekwizit] *n.* 先决条件
preselect ['pri:si'lekt] *v.* 预选
pretest ['pri:test] *n.* 事先试验，预先检验
prevailing [pri'veiliŋ] *a.* 占优势的，主要的
principal mineral 主要矿物
probe [prəub] *n.* 探测
product ['prɔdəkt] *n.* 乘积
profile ['prəufail] *n.* 轮廓，剖面
profound [prə'faund] *a.* 极度的
progressively [prə'gresivli] *adv.* 日益增多地
project ['prɔdʒekt] *v.* 发射
projecting [prə'dʒektiŋ] *a.* 伸出的
projection [prə'dʒekʃən] *n.* 凸出，投影
prominence ['prɔminəns] *n.* 突起
propagate ['prɔpəgeit] *v.* 传播
propagation [ˌprɔpə'geiʃən] *n.* 传播
propel [prə'pel] *v.* 推进
proprietary [prə'praiətəri] *n.* 私人拥有
propulsion [prə'pʌlʃən] *n.* 推进
protrude [prə'tru:d] *v.* 伸出
prudent ['pru:dənt] *a.* 谨慎的，慎重的
pry [prai] *vt.*(用工具)撬起，撬开，撬动
psi =pound per square inch 磅/平方英寸
pulverize ['pʌlvəraiz] *v.* 研磨成粉
pumice ['pʌmis] *n.* 浮岩
pumpable ['pʌmpəbl] *a.* 可用泵抽的
pumping-out test 抽水试验
purification [ˌpjuərifi'keiʃən] *n.* 纯化，提纯
push out 推出
pyrometamorphism [ˌpaiərəuˌmetə'mɔ:fizəm] *n.* 高热变质
pyroxene [pai'rɔksi:n] *n.* 辉石

Q

quantitatively ['kwɔntitətivli] *adv.* 数量上
quarry ['kwɔri] *n.* 采石场，石坑
quartz [kwɔ:ts] *n.* 石英
Quebec [kwi'bek] *n.* 魁北克(加拿大省名)

R

radial ['reidjəl] *adv.* 径向的，放射状的
raft [rɑ:ft] *n.* 筏
ram [ræm] *vt.* 锤击，振动
ramp [ræmp] *n.* 斜坡，坡道
rate [reit] *vt.* 以某种方式划分等级
ratio ['reiʃiəu] *n.* 比率，系数
ravel ['rævəl] *v.* 剥落
reactant [ri:'æktənt] *n.* 反应物

reaction [ri(:)'ækʃən] *n.* 反应
rear [riə] *n.* 后部
rearrangement [ˌri:ə'reindʒmənt] *n.* 重新配置，调整
rebind ['ri:'baind] *v.* 再胶结
rebound [ri'baund] *n.* 回弹；*v.* 回弹，反弹
reclamation [ˌreklə'meiʃən] *n.* 开垦
redistribute ['ri:dis'tribju(:)t] *vt.* 重新分配，重新分布
refer to 引用
reference to 查阅，参考
refine [ri'fain] *vt.* 精制，精炼，提纯
regardless of 不管，不顾
register ['redʒistə] *n.* 记录表
rehabilitation ['ri:(h)əˌbili'teiʃən] *n.* 恢复
reinforcement [ˌri:in'fɔ:smənt] *n.* 钢筋，加强
reliable [ri'laiəbl] *a.* 可靠的，可信的
relieve [ri'li:v] *v.* 减轻
remainder [ri'meində] *n.* 剩余，残余
remedial [ri'mi:djəl] *a.* 修补的，改造的
reorient [ˌri:'ɔ:rient] *v.* 再改方向，再定方位
requirement [ri'kwaiəmənt] *n.* 需求量
resemble [ri'zembl] *vt.* 像，类似
reservoir ['rezəvwɑ:] *n.* 水库，蓄水池
residential [ˌrezi'denʃəl] *a.* 居住的
resin ['rezin] *n.* 树脂
resistance [ri'zistəns] *n.* 阻力，抗力，抗蚀性
resistant [ri'zistənt] *a.* 抵抗的，有抵抗力的
restraint [ris'trein] *vt.* 约束力
resultant [ri'zʌltənt] *a.* 综合的
resume [ri'zju:m] *vt.* 再恢复
retaining wall 挡土墙
reversal [ri'və:səl] *n.* 反转，反向
review [ri'vju:] *n.* 评论，回顾
rhyolite ['raiəˌlait] *n.* 流纹岩
ridge [ridʒ] *n.* 脊，山脊
right [rait] *a.* 直角的，正交的
right angle 直角
riverbed ['rivəbed] *n.* 河床
roadcut [rəudkʌt] *n.* 路堑
rock unit 岩石地层单位
rockbolt ['rɔkˌbəult] *n.* 岩栓，岩石锚杆
rockburst *n.* 岩爆
rod [rɔd] *n.* 条，杆
roll [rəul] *v.* 轧制；*vt.* 使滚(转)动
root [ru:t] *n.* 根，根部
roundness ['raundnis] *n.* 圆度
rug [rʌg] *n.* (小)地毯，垫子
rupture ['rʌptʃə(r)] *n.* 断裂
rust [rʌst] *n.* 氧化，上锈，铁锈

S

safe from 免于遭受……之患
salinity [sə'liniti] *n.* 盐分，盐度
salmon ['sæmən] *n.* 鲑鱼
sand dune 沙丘
sandstone ['sændstəun] *n.* 砂岩
saturated ['sætʃəreitid] *a.* 湿透的，饱和的
sausage ['sɔsidʒ] *n.* 香肠
scaling ['skeiliŋ] *n.* 按比例
scarp [skɑ:p] *n.* 崖，陡坡
scatter ['skætə] *v.* 分散
scour ['skauə] *v.* 冲刷，疏浚
scrape [skreip] *vt.* 刮，擦
screw [skru:] *v.* 拧紧
seal [si:l] *v.* 密封
seam [si:m] *n.* 矿层，煤层，层间薄层
seamy ['si:mi] *a.* 有缝的，有疤痕的
section ['sekʃən] *n.* 剖面，刃口
sediment ['sedimənt] *n.* 沉积[物]，沉积物
sedimentary [sedi'mentəri] *a.* 沉积的，由沉积物形成的
sedimentary formation 沉积岩层，沉积构造
seepage force 渗流力

segment ['segmənt] *n.* 片
seismic ['saizmik] *a.* 地震引起的，与地震有关的
seismic waves 地震波
selective [si'lektiv] *a.* 选择的，选择性的
sensitivity analysis 敏感性分析
serpentine ['sə:pəntain] *n.* 蛇纹石，蛇纹石类，蛇纹岩
shaft [ʃɑ:ft] *n.* 竖井，矿井，坑道
shale [ʃeil] *n.* (油)页岩
shallow foundation 浅基础
shank [ʃæŋk] *n.* 螺钉的无纹部分
sharpen ['ʃɑ:pən] *v.* 削尖
shatter ['ʃætə] *vt.* 破碎，爆破
shear [ʃiə] *n.* & *v.* 剪切，剪(应变)
sheath [ʃi:θ] *n.* 鞘，外壳
sheer [ʃiə] *a.* 垂直的
sheet [ʃi:t] *n.* 板
shell [ʃel] *n.* 套管
shield [ʃi:ld] *n.* 盾
shock metamorphism 震动变质作用
shotcrete [ʃɔtkri:t] *n.* 喷混凝土
shove [ʃʌv] *v.* 推动
Siberia [sai'biəriə] *n.* 西伯利亚
side view 侧面图
sidewalk ['saidwɔ:k] *n.* 人行道
significant [sig'nifikənt] *a.* 值得注意的
silica ['silikə] *n.* 硅，二氧化硅
silicate ['silikit] *n.* 硅酸盐
silicon ['silikən] *n.* 硅，硅元素
sill [sil] *n.* 基石，[地质]岩床
silt [silt] *n.* 淤泥，粉砂，泥沙
simultaneous [ˌsiməl'teinjəs] *a.* 同时发生的
skeleton ['skelitən] *n.* 骨架，框架
sketch [sketʃ] *n.* 略图，草图
slab [slæb] *n.* 厚平板，厚片；*v.* 切片，把……分成厚片
slab foundation 板基础
sleet [sli:t] *n.* 雨夹雪
slice [slais] *n.* 切片，薄片，分层
slide [slaid] *v.* 滑动，山崩，地滑
slide down 滑落
sliver ['slivə] *n.* 薄片
slope [sləup] *n.* 边坡，斜坡
sluice [slu:s] *n.* 水闸
slurry ['slə:ri] *n.* 稀浆
soak [səuk] *v.* 浸，泡，浸透
sodium ['səudjəm, -diəm] *n.* 钠
soggy ['sɔgi] *a.* 潮湿的，浸水的
solidify [sə'lidifai] *n.* 凝固，结晶
solifluction ['sɔli'flʌkʃən] *n.* 融冻泥流
solubility [ˌsɔlju'biliti] *n.* 溶解度，溶解性
solute ['sɔlju:t] *n.* 溶解物，溶质
solution [sə'lu:ʃən] *n.* 溶液
solvent ['sɔlvənt] *n.* 溶剂
sorting ['sɔ:tiŋ] *n.* 分选
sound [saund] *a.* 坚固的，合理的
Soviet union 苏联
spall [spɔ:l] *n.* & *v.* 剥落，散裂，裂开
species ['spi:ʃiz] *n.* 种类
specific [spi'sifik] *a.* 具体的，单位的
specific discharge 比流量，渗透速度
specific weight 比重
spectacular [spek'tækjulə] *a.* 引人入胜的，壮观的
spectrum ['spektrəm] *n.* 领域，范围，系列
spillway ['spilwei] *n.* 溢洪(泄洪)道
spiral ['spaiərəl] *a.* 螺旋的
spontaneous [spɔn'teinjəs, -niəs] *a.* 自发的，自然的
spontaneously [spɔn'teinjəsli, -niəsli] *adv.* 自然地，本能地
spoon [spu:n] *n.* 匙，调羹，勺子
spray [sprei] *n.* 浪花
square centimeter 平方厘米
squeeze [skwi:z] *v.* 挤

stability [stə'biliti] *n.* 稳定性
stabilometer [ˌsteibi'lɔmitə] *n.* 稳定仪
stain [stein] *v.* 染污，沾污
stake [steik] *n.* 木桩
static ['stætik] *a.* 静止的，固定的
steer [stiə] *v.* 驾驶，向……行驶
stiffness ['stifnis] *n.* 刚性(度)，硬度
stishovite ['stiʃəˌvait] *n.* 超石英(比重为4.2 的高压变体石英)
strain [strein] *v.* 拉紧，扯紧
strain rate　应变率
strata ['streitə] *n.* 层，地层，岩层
stratification [ˌstrætifi'keiʃən] *n.* 层理，地层
stratified ['strætifaid] *a.* 分层的，成层的
stratum [streitəm] *n.* 地层
stress [stres] *n.* 应力
stretch [stretʃ] *v.* 伸展，伸长
strike [straik] *n.* 走向
strip [strip] *n.* 条，带
structural basin　构造盆地
structural dome　构造穹窿
stuck [stʌk] *n.* 黏性
subduct [sʌb'dʌkt] *vt.* 下转，向下压或向下拉
subducting plate　俯冲板块，消减板块
sub-parallel ['sʌb'pærəlel] *n.* 略平行
subside [səb'said] *vi.* 下沉
subsidence ['sʌbsidəns] *n.* 下沉，沉降
subsoil ['sʌbsɔil] *n.* 下层土
substantial [səb'stænʃəl] *a.* 坚固的，坚实的，具体的
substructure [sʌb'strʌktʃə] *n.* 下部结构
subsurface ['sʌb'sə:fis] *n.* 地表下的岩石[土壤]，水面下的水层；*a.* 地面下的
subterranean [sʌbtə'reiniən] *a.* 地球内的
suction ['sʌkʃən] *n.* 吸力，吸气
suggestive[sə'dʒestiv] *a.* 提示的，启发的，可作参考的
sulfur ['sʌlfə] *n.* 硫
sump ['sʌmp] *n.* 贮槽
sunken-tube tunnel　沉管隧道
superficial [sju:pə'fiʃəl] *a.* 表面的
superimpose ['sju:pərim'pəuz] *v.* 将某物置于另一物上，叠合
superplasticizer　*n.* 超可塑剂
surface wave　面波
surficial [sə:'fiʃəl] *a.* 地表的，地面的
surrounding rock　围岩
surveillance [sə:'veiləns] *n.* 监视(督)
survive [sə'vaiv] *v.* 幸存，生还
susceptible [sə'septəbl] *a.* 敏感的，易受影响的
swell [swel] *v.* 膨胀
swiftly [swiftli] *adv.* 很快地，即刻
swirl [swə:l] *vt.* 使成旋涡
symmetrical [si'metrikəl] *a.* 对称的，相称的
syncline ['siŋklain] *n.* 向斜

T

tabular ['tæbjulə] *a.* 片状的，薄层的
take root　生根，扎根
talus ['teiləs] *n.* 崩塌岩堆
tamp ['tæmp] *vt.* 夯实
tandem ['tændəm] *adv.* 一前一后
tangent ['tændʒənt] *n.* 切线，正切
taper ['teipə] *n.* 圆锥
tapered['teipəd]　*a.* 锥形的
TBE =Total Binding Energy　(核的)总结合能
tectonic [tek'tɔnik] *a.* 构造的
tectonic force　构造作用力
tectonic plate　构造板块
tensile ['tensail] *a.* 拉[张]力的
term [tə:m] *n.* 术语，专有名词
terrestrial [ti'restriəl] *n.* 地球的，大地的

Teton dam 提堂坝
tetrachloride [ˌtetrə'klɔːraid] *n.* 四氯化物
tetrahedral ['tetrə'hedrəl] *a.* 有四面的，四面体的
texture ['tekstʃə] *n.* 结构
thaw [θɔː] *v.* 融化，融解
the Almanza Dam 阿尔曼扎坝
the Great Lake 大西洋
the New Austrian Tunneling Method (NATM) 新奥地利隧洞施工法
the Nile River 尼罗河
the U.S. bureau of reclamation 美国垦务局
theoretical [θiə'retikəl] *a.* 理论的
thermodynamic ['θəːməudai'næmik] *a.* 热力学的
thread [θred] *n.* 螺纹，螺丝
threshold ['θreʃhəuld] *n.* 临界(值)
threshold gradient 临界梯度
thrust [θrʌst] *n.* 推力
thrust fault 冲断层
tick [tik] *n.* 记号，勾号
tie [tai] *n.* 拉杆
tight [tait] *a.* 致密的，紧密的，不漏水(不透气)的
tilted [tiltid] *a.* 倾斜的，翘起的
timber ['timbə] *n.* 原木
tombstone ['tuːmstəun] *n.* 墓石，墓碑
topography [tə'pɔgrəfi] *n.* 地形，地貌
topple ['tɔpl] *v.* 倾覆
torque [tɔːk] *n.* 转矩，扭矩
tow [təu] *vt.* 拖
tract [trækt] *n.* 地区，区域，河段
transfer [træns'fəː] *v.* 传输，转移
transmit [trænz'mit] *vt.* 传送，透过
transport [træns'pɔːt] *vt.* 传送，运输
transverse ['trænzvəːs] *a.* 横向的
trap [træp] *n.* 槽，U 型井；*v.* 捕获，收集，关闭，封闭
trapejoid ['træpigəid] *n.* 不规则四边形
trapezoid ['træpizɔid] *n.* 阶梯形的
tremble ['trembl] *n.* 颤动
tremendous [tri'mendəs] *a.* 巨大的
trial [traiəl] *n.* 试验
trickle ['trikl] *vi.* 淌，细流
triple ['tripl] *n.* 三倍
trough ['trɔːf] *n.* 断槽，地槽
troughlike ['trɔːflaik] *a.* 槽形的
turbulent ['təːbjulənt] *a.* 紊流的，湍流的，涡旋的
typhoon [tai'fuːn] *n.* 台风
typical ['tipikəl] *a.* 典型的，标准的

U

ultimate ['ʌltimit] *a.* 基本的
ultramafic [ˌʌltrə'mæfik] *a.* 超基性的
undergo[ˌʌndə'gəu] *vt.* 经历，遭受，忍受
underlying ['ʌndə'laiiŋ] *a.* 在下面的，潜在的
undermine [ˌʌndə'main] *vt.* 潜挖
underpinning [ʌndə'piniŋ] *n.* 拖换基础
unevenly ['ʌniːvənli] *adv.* 不平地
uniaxial ['juːni'æksiəl] *a.* 单轴的
uniaxial compressive strength 单轴压缩强度
unravel [ʌn'rævəl] *vt.* 解开，拆开
uplift [ʌp'lift] *n.* 举起，升起，隆起，扬压力，浮力；*v.* 举起，升起，隆起

V

vacuum ['vækjuəm] *n.* 真空
Vaksh river 瓦赫什河
vector ['vektə] *n.* 向量，矢量
vegetation [vedʒi'teiʃən] *n.* 植被
vehicular [vi'hikjulə] *a.* 车辆的
velocity [vi'lɔsiti] *n.* 速度
version ['vəːʃən] *n.* 方案，形(式)， 版本
via ['vaiə, 'viːə] *prep.* 经，通过，经由

vibrate [vai'breit] *v.* 振动，振荡
viscosity [vis'kɔsiti] *n.* 黏质，黏性
viscous['viskəs] *a.* 黏性的，黏稠的
visualize ['vizjuəlaiz, 'viʒ-] *v.* 目测，设想，显象
void [vɔid] *n.* 孔隙，孔率，空洞
volatile ['vɔlətail] *n.* 挥发物
volcano [vɔl'keinəu] *n.* 火山
volumetric [vɔlju'metrik] *a.* 测定体积的
vulnerable ['vʌlnərəb(ə)l] *a.* 易受攻击的，易受……的攻击

W

water phase 水相
water/cement ratio 水灰比
waterborne ['wɔ:təbɔ:n] *a.* 水生(成、运)的
waterlogged ['wɔ:təlɔgd] *a.* 饱水的
watermelon ['wɔ:təmelən] *n.* 西瓜
wavelike ['weivlaik] *a.* & *adv.* 波浪般的(地)，波状的(地)
weakened zone 软弱带
weather ['weðə] *vt.* 侵蚀；*vi.* 风化
weathering ['weðəriŋ] *n.* 风化作用
wedge [wedʒ] *n.* 楔形体，楔形物；*vt.* 楔入，楔进
weep [wi:p] *n.* 排水
weighted ['weitid] *a.* 加权的，权重的
well sorted 分选良好的
white-water ['hwait,wɔ:tə, -,wɔtə,'wait-] *a.* 白浪的
windblown ['windbləun] *n.* 风蚀的，风积的
wire mesh 铁丝网
Wisconsin [wis'kɔnsin] *n.* 威斯康星州 (美国州名)
with provision for 考虑到
with respect to 关于，至于
woodworm 木蛀虫
work [wə:k] *n.* 工程
workmanship ['wə:kmənʃip] *n.* 工艺，技巧
wreak [ri:k] *v.* 施加，造成
wrench [rentʃ] *n.* 扳手

Y

yellowish ['jeləuiʃ] *a.* 微黄色的

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